

RUSSIAN DANDELION

(KOK-SAGHYZ)

An Emergency Source of Natural Rubber

Compiled by W. GORDON WHALEY, *senior geneticist, Rubber Plant Investigations, Bureau of Plant Industry, Soils, and Agricultural Engineering*, and JOHN S. BOWEN, *assistant executive officer, Emergency Rubber Project, Forest Service*¹

THE RUBBER EMERGENCY

NEED FOR AN EMERGENCY SOURCE OF RUBBER

In 1939 the United States consumed 592,000 long tons of natural rubber, 53 percent of the world total. By 1941 the demands of lend-lease, the military forces, and an expanded civilian economy had increased annual consumption to 775,000 long tons. Despite this increased demand a stock pile of 630,300 long tons was amassed by April 1942 (12).² However, by this time Japanese conquests had cut off 90 percent of the available supply. During the years just previous, 97 percent of the world's rubber had come from hevea plantations in the Far East, including Ceylon. The remaining 3 percent was obtained from hevea elsewhere and such secondary sources as castilla and guayule and included a negligible quantity of synthetic rubber.

It was recognized early in 1942 that the stock pile of natural rubber would be inadequate to meet the demands, and that substitutes for hevea rubber in the form of natural rubber from other plants and of synthetic rubber must be found or developed at the earliest possible date.

¹ This compilation is based directly on the report of H. Basil Wales, Field Director, Emergency Rubber Project, Kok-saghyz, Forest Service, which is in turn a summary of reports of Forest Service project and experiment station personnel; and the reports of Clarence E. Steinbauer, Crop Research Leader, Rubber Plant Investigations, Bureau of Plant Industry, Soils, and Agricultural Engineering; Roderick K. Eskew, Head, Chemical Engineering and Development Division, Eastern Regional Research Laboratory, Bureau of Agricultural and Industrial Chemistry; and of other field and research organizations.

Data from the original reports have been amended, annotated, and interpreted in the light of developments subsequent to their preparation.

The introductory sections on The Rubber Emergency and The Discovery and Development of Kok-saghyz by the Russians have been written in part by E. W. Brandes, Head Pathologist, Rubber Plant Investigations, Bureau of Plant Industry, Soils, and Agricultural Engineering.

² Numbers in parentheses refer to references cited in bibliography, p. 184.

To understand and evaluate properly the investigations of possible emergency sources of rubber made during the war years, one must consider these investigations against the background of the need for rubber and the earlier planning and work done to insure rubber supplies.

DEVELOPMENTS PRIOR TO THE FORMULATION OF A NATIONAL RUBBER POLICY

The magnitude of the problem presented by the Japanese conquest of Malaya and the Netherlands East Indies can be visualized when it is remembered that, in terms of dollars, rubber was for several years before the war America's number one agricultural import. With Far Eastern sources of this strategic material cut off and supplies virtually nonexistent in other parts of the globe, the task at hand was nothing less than obtaining elsewhere, and in desperate haste, the vital substance that supported a group of the world's large important industries manufacturing absolutely necessary military and civilian goods.

Thanks to American commercial interests there were outside of the conquered area scattered rubber-growing enterprises, both producing and experimental, in North America, South America, and Africa. Exploitation of wild guayule rubber was begun by the Intercontinental Rubber Company in northern Mexico early in the present century. This same company established plantings of guayule in Arizona and later at Salinas, California, where a commercial extraction factory was erected. This venture was still in existence on a modest scale when the war began.

During the later years of his life Thomas A. Edison carried out a series of experiments with rubber-bearing plants to determine specifically whether there might be some plant adapted to growth in the United States and which might in an emergency be grown and harvested annually by mowing or other mechanical means. Edison finally selected goldenrod as most promising. At his death his collection of selected goldenrod varieties was given to the United States Department of Agriculture for further trials.

The Ford Motor Company and the Goodyear Rubber Plantations Company had established the beginnings of hevea rubber plantations in Brazil and Central America, respectively, and, in a more notably successful venture the Firestone Rubber Company had developed a producing rubber plantation in Liberia.

In 1939 these few enterprises essentially represented the total of American commercial efforts in natural rubber production in areas destined to remain in Allied hands. Except the attempt to produce cultivated guayule, not one of any consequence was located in the United States.

The strategic importance of building up a revolving stock pile of rubber under Government control had been recognized in 1938 by the Department of Agriculture and the War Department. The trading of surplus cotton for rubber was proposed by Secretary of Agriculture Wallace on April 10, 1939, and a bill was introduced in Congress July 21 authorizing such a barter project. Under the provisions of this bill, passed August 11, 1939, 600,000 bales of cotton were traded for 90,000 tons of rubber which formed the nucleus of the emergency stock pile.

Further active steps toward insuring a supply of rubber were taken in June 1940 when Congress authorized, mainly on the basis of recommendations by the Departments of State and Agriculture, an expanded investigation by the Department of Agriculture. This investigation was to be directed toward the development of rubber production in the Western Hemisphere, including production, breeding, and disease research, surveys of potential rubber-producing areas, and establishment and operation of experiment and demonstration stations in suitable locations. The funds made available to the Department were allocated to the Bureau of Plant Industry and greatly increased the scope of that Bureau's heretofore modest investigations on rubber production.

The initial work under this appropriation emphasized the study and plantation development of the Para rubber tree in the western tropics as a long-term program. When war engulfed the United States a year later part of the emphasis was shifted to potential domestic emergency rubber crops.

Along with the programs for natural rubber came demands for action in the development of synthetic rubber. In May 1941 construction of synthetic rubber plants with an annual capacity of 40,000 tons of GR-S (butadiene-styrene type) was begun. Then in June a bill was introduced in Congress which provided for planting 45,000 acres of guayule in the United States.

The directors of the Intercontinental Rubber Company offered to sell to the United States their entire holding including their extraction mill, field plantations, nurseries, and seed, together with patents, experimental data, and records.

Increased exploitation of wild rubber was initiated in December 1941 by the Office of the Coordinator of Inter-American Affairs working in close collaboration with the Department of Agriculture. Later this responsibility was taken over by the Rubber Development Corporation. During the years 1942-44, inclusive, this effort provided more than 100,000 tons of natural rubber for emergency needs of the United States.

FORMULATION OF A NATIONAL RUBBER PROGRAM

The dependence of the United States on far distant sources of natural rubber became a cause for immediate concern with the outbreak of the war in Europe, and as the conflict spread this concern increased.

Persons acquainted with the problems of supply and usage of natural rubber recognized the selective nature of the legitimate demands upon the limited stock pile and the fact that reliance had to be placed not upon any one potential source of natural rubber but upon all sources that might fill specified integral parts of the need at the critical times. A listing of potential sources and a progressive timetable according to which rubber from these sources might be made available to meet the demands was prepared in the Department of Agriculture and distributed to other Government agencies in December 1941.

This timetable, which helped to crystallize later practical actions, recognized that chief dependence had to be placed upon synthetic rubber for timely production in quantity and upon natural rubber for special indispensable uses and for compounding with synthetic. It was clear that the meager resources of plantation hevea rubber in Africa would fall far short of meeting the need for indispensable natural rubber and attention was given two other sources, the increased exploitation of wild rubber in Mexico and tropical America and the production of rubber by cultivation of emergency rubber crops. In the timetable the prospect of filling the demand from the sources in this order was set forth and the schedule of potential rubber production was projected to the year 1950 on the assumption that the war and the need might continue unabated until that time.

Supplies of rubber from these emergency crop sources were beginning to become available when the progress of the war reached a point permitting a decrease in the estimated military requirements. Had the war continued longer, maintenance of the natural rubber stock pile would have depended principally on these hastily developed emergency crops.

Although in the early days of this country's involvement in the war there was no over-all national rubber policy, the crisis did not find the Nation wholly unprepared, or without resources in the nature of individual far-seeing statesmen, experienced rubber technicians, and others capable of anticipating and meeting with reasonable success the problems of rubber procurement. Timely action resulting from their recommendations did provide for the minimum critical military requirements until appreciable quantities of synthetic rubber became available.

Before the question of rubber supplies took on the appearance of

chaos, several steps had been taken to insure meeting the minimum requirements for natural rubber.

As a result of an over-all consideration of sources of rubber and the need for coordination of rubber procurement efforts by Federal agencies, an attempt was made early in 1942 to bring about the integration of Government programs for the production of synthetic rubber in quantity and provision of necessary amounts of natural rubber to vitalize and extend the usefulness of the synthetic-natural rubber mixtures. This attempt took the form of a resolution submitted in the House of Representatives March 11, 1942, by Congressman Ross Collins, calling for "an immediate consolidation under a capable director of all existing Federal agencies having to do with the production, directly or indirectly, of natural and synthetic rubber."

This resolution eventually focused attention on the growing need for unity in the Government agencies having to do with rubber production. On August 6 of the same year a committee of inquiry was appointed by the President to survey the rubber situation and "include not only facts with respect to existing supplies and estimates as to future needs but also the question of the best methods to be followed for obtaining an adequate supply of rubber for our military and essential civilian requirements."

A report from this committee, whose deliberations had centered mainly around the need for synthetic rubber production in quantity, was made by the chairman, Bernard M. Baruch, to the President September 10, 1942 (5). It included recommendations for the conservation of tires for essential civilian use by rationing of gasoline and by limiting speed of civilian passenger cars and trucks to 35 miles per hour, for rapid development of synthetic rubber in quantity, and for increase of natural-rubber production from all available sources. It also recommended a complete reorganization and consolidation of the Government agencies concerned with the rubber program and appointment by the Chairman of the War Production Board of a Rubber Administrator to whom would be delegated full and complete authority in all matters relating to rubber, including research, development and construction and operation of synthetic-rubber plants.

In accordance with a Presidential Executive Order of September 17, 1942, which followed the recommendation of the Baruch Committee, the Chairman of the War Production Board appointed a Rubber Director to consolidate the work of the Government agencies concerned with the rubber program. The Office of the Rubber Director gave almost exclusive attention to the production of synthetic rubber and only secondary attention to the production of natural rubber, which, however, was recognized in its reports as essential for military and "heavy duty" requirements.

The stock pile, the plantation rubber from Liberia and Ceylon, and the wild rubber from the tropics and northern Mexico together were found by the committee to be insufficient in the light of expected military and essential civilian demands for natural rubber if the war should continue beyond 1945. Still other sources would be needed and steps were taken to produce rubber from plants which could be grown within the continental United States.

ESTABLISHMENT OF THE EMERGENCY RUBBER PROJECT

THE ORGANIZATION OF KOK-SAGHYZ INVESTIGATIONS

By Act of Congress, approved March 5, 1942 (Public Law 473—77th Congress), the Secretary of Agriculture was authorized to purchase the property of the Intercontinental Rubber Company, to proceed with the production of guayule, and “to exercise with respect to rubber-bearing plants *other than guayule* the same powers as are granted * * * with respect to guayule.” [Italics are authors’.]

The Secretary’s memorandum 991, dated March 12, 1942, designated the Forest Service as the Department agency responsible for the administration of the program and directed the Bureau of Plant Industry to undertake the necessary research (42p). The Forest Service was authorized to call on any other bureaus in the Department whose services were necessary or desirable. The Bureau of Agricultural and Industrial Chemistry was requested to conduct research on extraction and rubber evaluation, and the Bureau of Entomology and Plant Quarantine, studies in insect control.

Under the authority of the aforementioned law, the Department of Agriculture made plans for an extensive program of investigation and field tests of kok-saghyz, the so-called Russian dandelion, as an emergency source of rubber and submitted them for approval of the policy-making agencies.

A summary (35p) was prepared giving the results of the tests initiated by the Bureau of Plant Industry and the Forest Service in May 1942 when a shipment of kok-saghyz seed was received in this country. A prospectus was also prepared outlining the results of those tests and including a plan for possible expanded production by utilizing all the planting materials then on hand (42p). This prospectus was presented by the Secretary of Agriculture to the Rubber Director, War Production Board, in January 1943. The Rubber Director was asked for a decision whether the current and projected military and civilian needs for natural rubber made desirable the initiation of a kok-saghyz program as an emergency measure of rubber insurance.

The Rubber Director, however, decided that further experimentation and research upon plantings of several hundred acres should be undertaken in 1943 so that the problems of production might be adequately determined. He deferred decision on the production

program until results obtained from large-scale 1943 field experiments had been evaluated.

Immediately upon receipt of the Rubber Director's decision, representatives of cooperating bureaus of the Department of Agriculture worked out the guiding details of the organization and an enlarged experimental program involving field-scale production and research on the adaptability of kok-saghyz, development of cultural methods and machinery, extraction processes up to the pilot plant stage of operation, and related problems.

The Forest Service designated the Regional Forester at Milwaukee, Wis., responsible for planning, organizing, and administering the program and for integrating the production trials with the experimental and research phases to be conducted by the cooperating agencies. The work under the Regional Forester was to be handled by a field director appointed by and responsible to him. The Director of the Lake States Forest Experiment Station was designated as the liaison officer between the Regional Forester and the other Forest Experiment Stations concerned with the program.

The Bureau of Plant Industry, to which was delegated responsibility for research within its field, designated a crop research leader and set up a field station at University Farm, St. Paul, Minn., in cooperation with the University of Minnesota. Soil studies were conducted under direction of a soils advisor with headquarters in Beltsville, Md. Machinery development was also carried on at Beltsville under guidance of an agricultural machinery adviser, who operated from summer headquarters in St. Paul.

Processing and extraction research was assigned by the Bureau of Agricultural and Industrial Chemistry to the Director of the Eastern Regional Research Laboratory in Philadelphia, Pa.

Regions having what were then thought to be requisite soil and climatic conditions were surveyed for representative areas in which to establish large scale production tests. In these surveys attention was given to availability of land and labor, and to other economic factors as well as to facilities for carrying on the projected experiments. The following distribution of field test planting was decided upon: Vermont, 10 acres; New York, 60 acres; Michigan, 120 acres; Wisconsin, 40 acres; Minnesota, 400 acres; Montana, 60 acres; Oregon, 60 acres. There was also to be a carryover of 1942 plantings, dictated by the availability of good stands, as follows: Manistique, Mich., 20 acres; Cass Lake, Minn., 30 acres; Miles City, Mont., 1 acre; Missoula, Mont., 1 acre; and Savenac, Mont., 1 acre.

In addition to plantings at these locations, smaller indicator plantings were to be made at several other places. The program was de-

signed to determine further the adaptability of the plant and to discover the problems of growing the plant on a large scale, harvesting it, and extracting the rubber. It was also hoped that the yield and quality of rubber, as well as costs of production, might be determined. As additional objectives, the program was to produce sufficient roots to supply a pilot mill and seed to permit rapid expansion.

A detailed description of the organization of the Emergency Rubber Project (kok-saghyz) is given in Wales' report (42p). Wales includes a historical summary of the legislation and appropriations which authorized and financed the project, together with a summary of its personnel structure, outlining in detail the various interagency cooperations involved. He also gives attention to the public relations phases of the project.

KOK-SAGHYZ AS A SOURCE OF RUBBER

Russian experience with kok-saghyz, at least in its main aspects if not in detail, was known to individuals in the Bureau of Plant Industry in the early 1930's. L. G. Polhamus of that bureau had discussed the work, then in its incipency, with the Russian botanist Vavilov during a visit of the latter to the United States and had requested seed which, however, was not obtained. In 1938 E. W. Brandes of the Bureau of Plant Industry inspected greenhouse and field plantings of kok-saghyz in Leningrad with Vavilov. At that time the outlook for the crop in the U. S. S. R. was still clothed with uncertainty and further negotiations for seed were without success. The information gained through the establishment and maintenance of first-hand contacts with Russians and Americans in the U. S. S. R. proved useful when in late 1941 the practical problem of obtaining seed arose.

Initiation of the intensive investigation of Kok-saghyz in the Western Hemisphere reported in this publication began with the importation of 187 pounds of seed which arrived in Washington in May 1942 by air from Kuibyshev. The seed procurement and its immediate distribution by air to 60 stations for comparative tests in the New World is described by Brandes (11a).

The success of these early adaptability tests (35p), made with this first shipment of seed, and the availability of larger supplies of seed later on encouraged the Department of Agriculture to recommend the field-scale experimental program which was approved.

Wartime American experience with kok-saghyz as a potential emergency source of rubber constituted a unique plant introduction and testing program. In breadth of conception, both as to geographic scope and intensity of the program of research and testing conducted under pressure of time limitations, it is unexampled in the annals of plant introduction.

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PREFACE

Inasmuch as no kok-saghyz had been grown in this country before early 1942 and as almost no background information about the growing of kok-saghyz for rubber production was available, the value of recording detailed data was recognized when the Emergency Rubber Project was started. Provision was made for collection, tabulation, and evaluation of such data and for preparation of reports by members of the project as well as by cooperating individuals and agencies. Frequent review of these field and laboratory reports furnished a background for planning the developing program.

The periodic reports of the project's field personnel and associated investigators were assembled and evaluated shortly after the close of the field program by the Field Director in a mimeographed report, *The Production of Kok-saghyz as a Source of Emergency Rubber*. Careful weighing of all the data in this and other original reports and their examination in retrospect, without need for reference to the demands and pressures of wartime situations, gives a markedly different aspect to certain of the suggestions and conclusions.

This publication is a summary of the investigations conducted between early summer 1942 and June 1944, when the attempt at large scale experimental production of kok-saghyz was terminated. It is primarily a record of field-scale production tests conducted by the Forest Service and allied research by the Bureau of Plant Industry, Soils, and Agricultural Engineering; Bureau of Agricultural and Industrial Chemistry; Bureau of Entomology and Plant Quarantine; and several colleges, universities, State experiment stations, and other cooperating agencies and individuals. It is intended to serve as a general reference, an index of kok-saghyz publications, and a guide to future investigation of kok-saghyz.

Of the numerous articles describing Russian investigations of kok-saghyz only a few have been cited directly as references. Many more are listed in the bibliography. Translations of some of these Russian papers are available in the library of the United States Department of Agriculture, Washington, D. C.

While many results of Russian investigations had been published before 1942, the unfamiliarity of American scientists with Russian publications and the difficulties involved in obtaining material, particularly during the years before the war, resulted in a dearth of knowledge concerning the only work which had been done with kok-saghyz. Difficulties in this line were accentuated by delay in trans-

lating and distributing publications received before initiation of the project and during its early months.

It is also unfortunate that the questions concerning production of kok-saghyz which were presented to the U. S. S. R. by the American Rubber Mission in the winter of 1942-43 and to Dr. P. S. Makeev, Vice Commissar for Natural Rubber in the U. S. S. R., following his visit to the project in the spring of 1943, remained unanswered. The information covered by these questions would have been particularly valuable during the field tests.

The detailed reports of the project and cooperating agencies and individuals which are listed in the bibliography are available for examination in the library of the United States Department of Agriculture, Washington, D. C. Many of these reports contain specialized information which has not seemed of sufficient general interest to warrant inclusion in this summary.

In compiling this general report free use has been made of the individual reports of all the members of the project and cooperating investigators. In each case credit has been given by name and bibliography reference number so that the findings or conclusions of the particular individual may be readily identified.

Reports on specific phases of kok-saghyz research appearing subsequent to publication of this general summary may be obtained by contacting the individual agencies conducting the research.

The compilers have had invaluable assistance in the form of guiding suggestions and critical reviews from a review board consisting of G. R. Salmond, Executive Officer, Emergency Rubber Project, Forest Service; W. R. Chapline, Division of Research, Forest Service; David H. Price, Chemical Engineer, Bureau of Agricultural and Industrial Chemistry; E. W. Brandes, Head Pathologist, Rubber Plant Investigations, L. G. Polhamus, Principal Agronomist, Rubber Plant Investigations, J. K. Ableiter, Division of Soils, and R. B. Gray, Division of Farm Power and Machinery, Bureau of Plant Industry, Soils, and Agricultural Engineering.

Acknowledgment is also due to Gleb Krotkov of the Department of Botany, Queen's University, Kingston, Ontario, Canada, for his interest and assistance, in which he combined his knowledge of Russian and of the plant to make careful reviews of the Russian publications on kok-saghyz.

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CONTENTS

	Page		Page
The rubber emergency	1	Experimental production—Con.	
Need for an emergency source		Planting areas—Continued	
of rubber	1	Moisture	34
Developments prior to the		Length of growing season ..	36
formulation of a national		Disease, insect, and other	
rubber policy	2	biological factors	37
Formulation of a national		Economic and other factors ..	37
rubber program	4	Cultural practices	37
Establishment of the Emergency		Seed testing and seed treat-	
Rubber Project	7	ment	37
The organization of kok-		Land selection	43
saghyz investigations	7	Ground preparation	44
Kok-saghyz as a source of		Soil fertility and fertiliza-	
rubber	9	tion	50
The general results of the		Time of sowing and its effect	
emergency program	10	on germination and emer-	
Discovery and development of		gence	53
kok-saghyz by the Russians ..	11	Sowing methods	56
Discovery of kok-saghyz	11	Germination and emergence ..	62
Efforts to domesticate and		Cultivation	65
improve kok-saghyz	11	Weeding	72
Experimental production of kok-		Roguing	76
saghyz rubber	12	Density, spacing, and thin-	
Nature of the kok-saghyz		ning	83
plant	12	Vegetative propagation	89
Botanical description	12	Transplanting	93
Habits of growth and de-		Diseases of kok-saghyz and	
velopment	12	their control	94
Flowering and seed forma-		Insects and other pests	98
tion	15	Eradication	100
Nutritional requirements ..	17	Seed production	103
Adaptability to different en-		Seed formation	103
vironmental conditions ..	18	Irrigation	105
Planting areas	18	Seed collection and yields ..	107
Soils	18	Seed threshing and cleaning ..	114
Relief	22	Seed storage	118
Texture	26	Root characteristics, root de-	
Reaction	27	velopment, and root har-	
Organic matter	27	vesting	120
Permeability	28	Form, size, and composition	
Moisture	28	of roots	120
Soluble salts and alkalis ..	28	Rubber formation	122
Temperature	29	Time of harvest	126
Summer	29	Method of harvest	128
Winter	31		

	Page		Page
Experimental production—Con.		Economics of production—Con.	
Root handling.....	134	Manpower requirements.....	161
Washing and drying.....	134	Equipment and materials re-	
Storage.....	136	quirements.....	164
Shipping.....	137	Improvement of the plant.....	166
Extraction methods.....	138	Increased rubber yield.....	166
Rubber.....	138	Seed improvement.....	169
Byproducts.....	141	Equipment development.....	170
Kok-saghyz rubber.....	142	Sampling and analyses.....	172
Yield.....	142	Summary of the experimental	
Quality and utility.....	145	work.....	174
Economics of production.....	148	Proposals for further investiga-	
Production costs.....	148	tions.....	178
Root production by direct		The potential value of kok-saghyz	
Government operation...	148	as a domestic source of natural	
Cost of extraction.....	154	rubber.....	181
Seed production by direct		Literature cited.....	184
Government operation...	156	Processed and typewritten re-	
Wage rates.....	158	ports.....	191
Contract growing of kok-		Additional literature.....	195
saghyz.....	159		

THE GENERAL RESULTS OF THE EMERGENCY PROGRAM

The results of the investigation indicate that kok-saghyz grows well over large areas in the United States and produces rubber of essentially the same high quality as hevea. However, the seed obtained from Russia produced plants so variable in form, habit of growth, and rubber content, with the average rubber yield so low, that costs of rubber production were excessively high. It was early apparent that the seed obtained from Russia represented essentially "wild" planting material, improved little or not at all over the plant as originally discovered.

Although the majority of plants grown were weak and contained relatively little rubber, selections of vigorous, high-yielding plants were made. Propagation of these selected strains, further improved by continued selection and breeding, is greatly increasing plant vigor and rubber yields, thereby making possible production at lower costs. Increased mechanization and improvement of cultural methods may be expected to lower costs still further.

DISCOVERY AND DEVELOPMENT OF KOK-SAGHYZ BY THE RUSSIANS

DISCOVERY OF KOK-SAGHYZ

The history of kok-saghyz begins in 1929 with the far-reaching investigations of Vavilov on the varietal composition of cultivated plants, their centers of origin and wild progenitors. These investigations were intended to explore the possibility of improving crop plants and of making the U. S. S. R. self-sufficient in strategic materials including vitally necessary rubber. Among the foreign and local expeditions of the Institute of Applied Botany (Leningrad), planned and in considerable part carried out by Vavilov, was a survey and study of plants of Central Asia made in 1931. Kok-saghyz was discovered by Rodin, a member of this expedition, on a high plateau of the Tien Shan Mountains in Kazakhstan just east of Alma Ata (2). By 1932 about 150 native and introduced rubber-bearing plants had been assembled and examined. Of these, kok-saghyz and 79 others were considered worthy of further study (22p).

EFFORTS TO DOMESTICATE AND IMPROVE KOK-SAGHYZ

After the collection of these rubber-bearing plants, studies were begun to determine the possibility of growing them in Russia as crops and to work out techniques of cultivation and production. By 1935 it was apparent that kok-saghyz was the most promising plant, and efforts were started to introduce it into cultivation on a wide scale.

In the judgment of the Russian scientists this plant combined the essential qualities of adaptation to conditions in the higher latitudes and the possibility of improvement into a satisfactory cultivated plant. Considerable work on improvement of the wild plant was started at agricultural experiment stations and concurrently seed was distributed to collective farms so that farmers might gain experience in handling a crop with which they were unfamiliar (22p).

In 1939 after several years' efforts average yields from Russian plantings were reported to be roughly equivalent to 20 pounds of seed and 25 pounds of rubber per acre (2).

A combined total of kok-saghyz plantings estimated at 50,000 acres was in cultivation in 1941 and on the expectation of plant improvement and better cultivation practices plans were made for a great expansion of this acreage.

EXPERIMENTAL PRODUCTION OF KOK-SAGHYZ RUBBER

NATURE OF THE KOK-SAGHYZ PLANT

Botanical Description

Taraxacum kok-saghyz Rodin, is a composite, readily recognizable as a dandelion. The plant consists of 25 to 50 leaves arranged at the crown or upper end of the root in one or more rosettes which may hug the ground closely or be somewhat erect (fig. 1). There is no distinct stem. The leaves are quite variable as to size but generally smaller than those of *T. officinale*, the common dandelion. There is also considerable variation as to leaf form, particularly the division or lobing of the margins. The leaves are usually somewhat thickened with prominent midribs and are generally grayish green in color. The flower stalks are slender, 8 to 10 inches long, and bear single flowerheads about one inch in diameter. Each head contains from 50 to 90 florets. A distinguishing species characteristic is the presence of projecting hornlike appendages at the tips of the bracts which surround the bud. Seeds are borne attached to parachutelike pappus, typical of dandelions.

For the complete botanical description of kok-saghyz, see Rodin (54).

Habits of Growth and Development

The basic requisite of any attempt to grow kok-saghyz as a source of rubber is a knowledge of the nature of the plant, its particular properties and characteristics, and its habit of growth and development. Inasmuch as no kok-saghyz had ever been grown in this country before 1942, it was necessary to depend upon such Russian descriptions of the plant and its growth as were available.

Russian attempts to cultivate kok-saghyz had revealed numerous characteristics of the plant's growth and development, some of which present problems in relation to satisfactory culture. Among the latter are dormancy of the seed, a high percentage of abnormal germination, slow germination, and a very weak and slowly developing seedling stage. These characteristics result in slow emergence and an extended period of weak seedling growth. This lack of vigor in the early growth stage exposes the plant to unfavorable effects of competition and multiplies problems of cultivation.

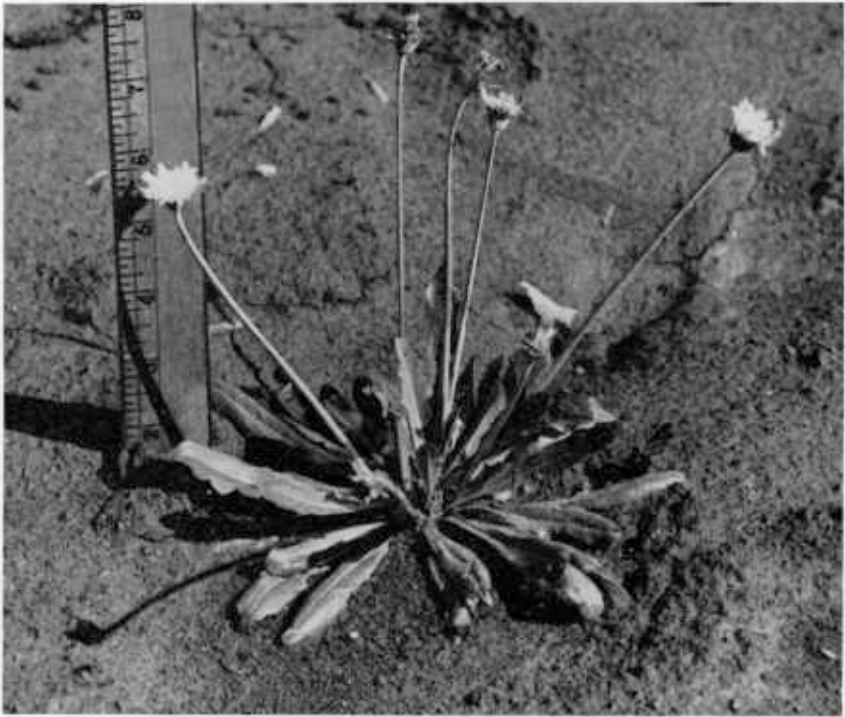


FIGURE 1.—An American-grown kok-saghyz plant in flower. (Courtesy of the Ford Motor Co.)

The production of rubber-bearing latex takes place in kok-saghyz largely in the root (fig. 2). Both the form and size of kok-saghyz roots appear to vary in plants of different genetic constitution as well as in response to environmental factors. In general, however, the plants are taprooted with more or less branching. In its native habitat the average dry weight of a root is approximately 1 gram (24). When grown in cultivation, roots are generally much larger.

The roots are thick, fleshy, and when fresh, brittle, and have a light colored surface. The internal structure of the kok-saghyz root undergoes marked changes during development. The number of latex tubes and their size, hence latex producing capacity, appears to increase in second year plants up to the time of seed formation. In the first year of growth rubber content appears to increase most rapidly in the last month or so of the growing season, that is, after seed production. The latex tubes are formed in secondary phloem, a tissue which in kok-saghyz, as in all perennial dandelions, is sloughed off during the year succeeding its formation (55). This sloughed-off tissue constitutes what in Russian publications has been called the glove (fig. 3).



FIGURE 2.—Roots of kok-saghyz. (Sovfoto.)

The glove may be composed of from one to several layers of sloughed-off tissue depending upon the age of the plant. Harvesting the root for rubber must precede this annual sloughing-off of secondary phloem containing latex tubes so as to avoid loss of the year's increment of rubber.

The seed which was received from Russia yielded plants showing an extremely great range of leaf types. Many of the plants were later found not to be kok-saghyz. However, plants classifiable as true *T. kok-saghyz* show a wide variation as to leaf form as well as to flowering habits, root form, and rubber content. In addition individual plants produce leaves of different shape at progressive stages of development.

There are numerous Russian papers suggesting correlations between leaf form and flowering habit, root size, rubber content, and other characteristics. Zehngraff's studies (45*p*) indicate correlations between flowering habit and rubber content as well as between leaf form, rubber content, and root size. However, the extreme heterogeneity of the experimental material available to both the Russian and American workers and the complexity of the biological factors

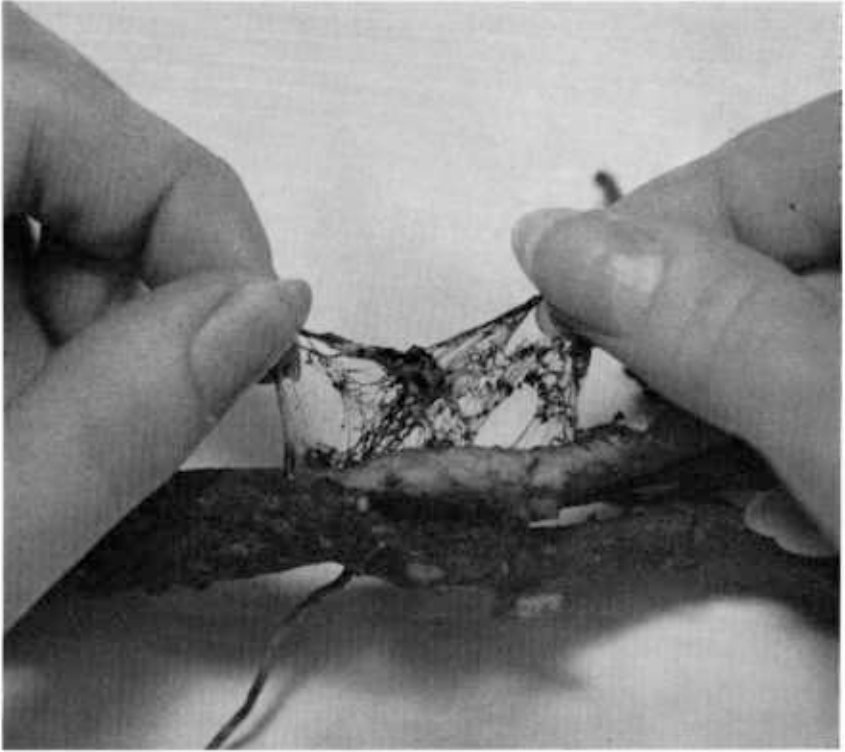


FIGURE 3.—The “glove” of accumulated rubber on the surface of the kok-saghyz root. (Bureau of Agricultural and Industrial Chemistry.)

affecting leaf form make it impossible at this time to reach any conclusions on the existence of such correlations.

While treated in most of the cultivation experiments as either an annual or as a biennial, in the wild, kok-saghyz appears to be a perennial plant. It grows actively until stopped by cold weather in autumn but most of the leaves remain green over winter. New growth which begins very early in the spring produces another rosette of leaves, and the old ones are rapidly lost.

Flowering and Seed Formation

Kok-saghyz normally reproduces by means of seed. There appear to be two types of plants, one of which begins to flower in the first season after sowing, and the other not until the second season. So far no observable characteristics other than the flowering habit have been found to distinguish these types. Under all conditions in which

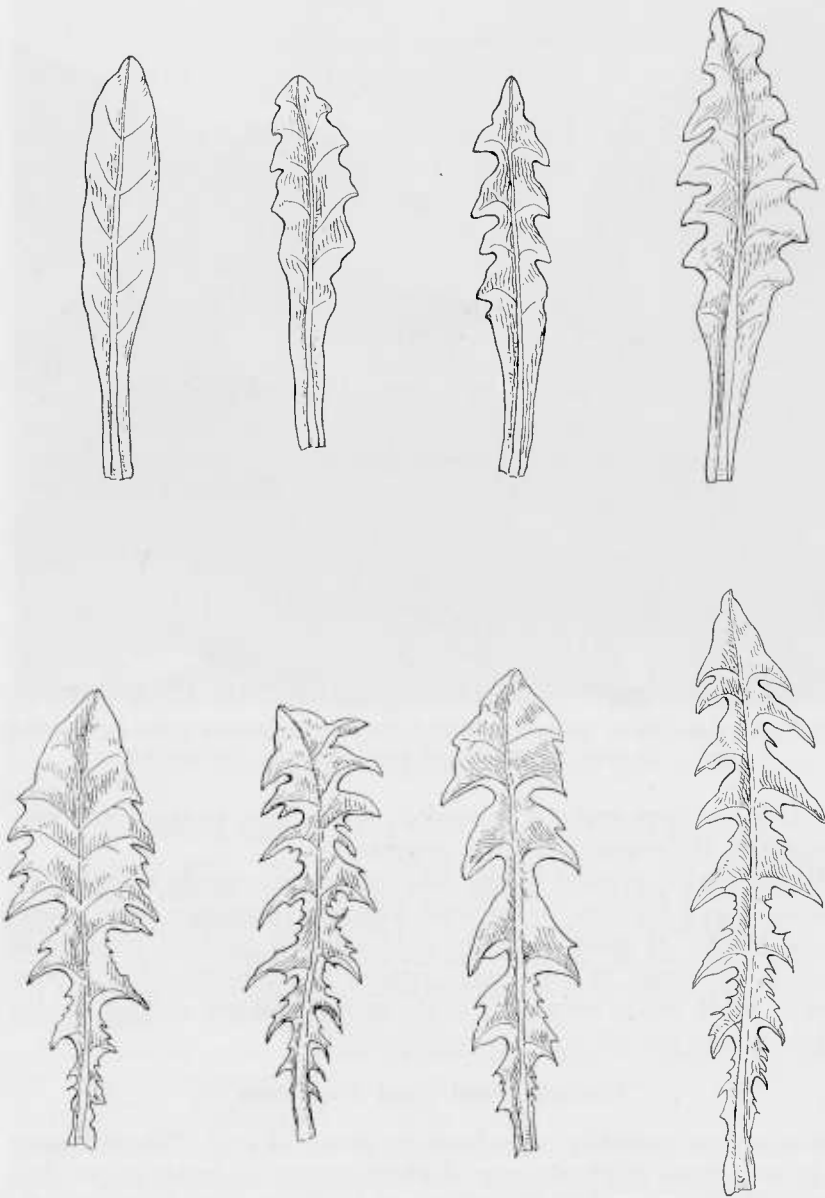


FIGURE 4.—Upper row—typical variations in the leaves of *Taraxacum kok-saghyz*.
Lower row—typical leaf variations among rogue forms.

they were grown, the first type began to flower 60 to 70 days after sowing and flowered until late autumn. In the second season in northern United States flowering begins in June for this type and there are two more or less distinct blooming periods. Both photoperiod and temperature have been demonstrated to exert a control over flowering.

Unlike some of the other dandelion species in which seeds are formed without fertilization (apomixis) kok-saghyz requires pollination. Koroleva (19) indicates that most pollination of kok-saghyz is by insects, principally bees, although there may be some transfer of pollen by wind. She says further that isolation studies indicate that the plant is primarily cross-pollinated. Warmke (64) and others have confirmed this last fact and the general evidence indicates that self-fertilization is infrequent.

Studies by Hamm (37*p*) show that the seed of kok-saghyz is composed of the following parts: a light brown to green brown spiny fruit coat; a thin papery outer seed coat which splits quite easily along lines of dehiscence and is apparently cellulosic with a waxy covering; a thin, leathery, tough inner seed coat, which remains intact around the embryo even after considerable manipulation but can be removed by tearing, and which apparently has no easily separated lines of dehiscence; and a well-developed embryo.

Koroleva has pointed out that kok-saghyz plantings in Russia have been characterized by a period of summer dormancy, usually following the flowering period. During the dormant stage growth ceases and some or all of the leaves die back. The appearance and duration of this dormant period seem to be dependent upon temperature, soil type, and other environmental conditions. This period comes to an end in late summer or early fall when active growth is resumed. At Bozeman, Mont., and Klamath Falls, Oreg., no such dormancy was noted. In other experimental plantings in this country this phenomenon of summer dormancy was much more common in the second year of growth than in the first.

Nutritional Requirements

The general requirements of kok-saghyz for well fertilized soils have been pointed out by several Russian investigators (34, 35, 36, 49) and confirmed by soil fertility studies made by Lewis (36*p*) and other investigators in this country.

Meyer (32) undertook a detailed analysis of the effects of deficiencies of certain mineral elements on kok-saghyz. He has reported that

a deficiency of nitrogen results in the production of only very small roots, and generally weak plants. A deficiency of either magnesium or potassium also results in marked lowering of root growth. The effect of calcium or phosphorus deficiencies is pronounced but considerably less deleterious. Meyer's studies suggest that the deficiencies which inhibit root growth also inhibit rubber formation.

In a more recent paper Meyer (33) states that maximum root yields in cultures were obtained with nutrient solutions containing 10 to 15 parts per million of boron. Thus, kok-saghyz appears much more tolerant of high concentrations of boron than most other plants and reacts unfavorably to deficiencies of boron.

Adaptability to Different Environmental Conditions

The natural restriction of kok-saghyz to a relatively small area of high mountain plateau might suggest that the plant would have rigid requirements for its growth. However, investigations of its adaptability both in Russia and the United States indicate that it will grow well over a wide range of soils and under varying conditions of climate, although it is definitely restricted to regions not having long-continued excessively hot temperatures.

PLANTING AREAS

Soils

Only general information is given in Russian papers regarding the soil requirements of kok-saghyz. Altukhov (2, 3) indicates that both Chernozems (black mineral soils) and organic soils are particularly suitable for kok-saghyz culture. He also indicates (2) that the soil must be rich in organic matter, in nitrogen and in phosphoric acid.

A U. S. S. R. Government announcement (62) advises farmers to select for kok-saghyz planting the best plots using first the peat soils under cultivation, truck garden plots, flood plains of rivers, and fertilized fields used previously for hemp cultivation.

In another publication (49) soils mentioned as being unsuitable for kok-saghyz are those that have poor structure, a crust after a rain, are too shallow, are poor in nutritive value, or are too light to retain water. In the same publication it is stated that better yields are obtained when the water table is within 1.5 to 2.0 meters of the surface.

Mikhailov (34) has pointed out that liming of acid podzol soils produces increases in root yield, rubber percentage, and total rubber yield.

As a result of adaptation and production tests in the summer of 1942 it was concluded that kok-saghyz is well adapted to the climatic conditions of northern United States, that is, north of a line drawn from southern New York west to southern Oregon, and that it will grow well on rich organic soils or on mineral soils with a high organic content.

Guided by these preliminary findings extensive testing of the adaptability of the plant to the various soils within this general region was undertaken in 1943 (26*p*). In all, plantings were made on 207 soil types in 161 localities in 41 States.

In general, the small experimental plantings at the State agricultural experiment stations were most useful for determining the climatic adaptation of kok-saghyz, whereas the larger field plantings were useful for determining specific soil requirements of the plant. The soils on which the plants were grown at the various State experiment stations were representative of the better soils within the respective States and, for the most part, were soils upon which vegetable crops had been successfully grown. Unusual soil profile conditions were largely eliminated by this choice and the differences in results reflected climatic and management differences more than soil differences. On the other hand, the Forest Service fields, although chosen so that the major portion of any one field consisted of suitable soils, were sufficiently large so that small inclusions of unsuitable soils occurred. These small inclusions were areas of poor drainage, hardpan, soluble salts, unfavorable slope, etc. The influence of these factors on plant growth in the smaller areas of the fields could be compared directly with the growth on the associated larger areas where these detrimental factors did not play a part and where plant growth was generally satisfactory.

The location of the plantings by broad soil regions (63) is given by seasons in table 1. Table 2 gives a summary of soil characteristics and crop history of lands used for kok-saghyz plantings.

TABLE 1.—*Results of kok-saghyz plantings made in 1942-43, by soil types and localities*

SPRING 1942

Soil region	Satisfactory results		Unsatisfactory results	
	Good	Fair	Poor	Failure
Mineral soils:				
Podzol.....		Sturgeon Bay, Wis.	Butternut, Wis. Manistique, Mich. Cass Lake, Minn. Haugan, Mont. Rhineland, Wis. Storrs, Conn. Paramus, N. J. Cold Spring Harbor, N. Y.	Ashland, Wis.
Brown Podzolic.....	Burlington, Vt.	Windsor, Conn. Storrs, Conn. New Haven, Conn.		
Gray-Brown Podzolic	Ithaca, N. Y. Geneva, N. Y. Madison, Wis.	Dearborn, Mich.	Beltsville, Md. Lancaster, Pa. State College, Pa. Wooster, Ohio. Corvallis, Oreg. Oregon City, Oreg.	Ithaca, N. Y. New Brunswick, N. J. East Lansing, Mich. Louisville, Ky. Frankfort, Ky. Powell, Ohio. Puyallup, Wash. Dixon Springs, Ill.
Red and Yellow Podzolic.				
Prairie.....	St. Paul, Minn. Berkeley, Calif.	Davis, Calif. Ames, Iowa. Lafayette, Ind. Manhattan, Kans.	Urbana, Ill.	Medford, Oreg. Talent, Oreg. Brownton, Ill. Floris, Iowa. North Platte, Nebr. Lincoln, Nebr. Hays, Kans. Hermiston, Oreg. Fort Collins, Colo. Laramie, Wyo. Klamath Falls, Oreg. Garden City, Kans. Miles City, Mont. Dickinson, N. Dak. Akron, Colo. Rocky Ford, Colo. Moscow, Idaho. Burns, Oreg. Moro, Oreg. Ontario, Oreg. Pendleton, Oreg. Lind, Wash. Prosser, Wash. El Centro, Calif. Shafter, Calif.
Chernozem.....	Brookings, S. Dak.	Fargo, N. Dak.	Bottineau, N. Dak.	
Chestnut or Brown	Bozeman, Mont. Klamath Falls, Oreg. Parma, Idaho.	Laramie, Wyo. Missoula, Mont. Moro, Oreg.	Toppenish, Wash. Union, Oreg. Pullman, Wash. Fort Lewis, Colo.	
Reddish Chestnut, Reddish Brown, Red Desert, or Noncalic Brown.		Capistrano, Calif. Riverside, Calif.		
Organic soils:				
Gray-Brown Podzolic	East Lansing, Mich.			
Prairie.....		Crystal Lake, Iowa.		

TABLE 1.—*Results of kok-saghyz plantings made in 1942-43, by soil types and localities—Continued*

FALL 1942

Soil region	Satisfactory results		Unsatisfactory results	
	Good	Fair	Poor	Failure
Mineral soils: Brown Podzolic Gray-Brown Podzolic				Storrs, Conn. Wooster, Ohio. Morgantown, W. Va. Blacksburg, Va. Poplarville, Miss. Sikeston, Mo. Stillwater, Okla. Blacksville, S. C. Clemson, S. C. Beeville, Tex. College Station, Tex. Denton, Tex.
Red and Yellow Podzolic.		Tifton, Ga.	Baton Rouge, La. Stoneville, Miss. Raleigh, N. C. Rocky Mount, N. C. Statesville, N. C. Willard, N. C. Auburn, Ala. Fayetteville, Ark. Marianna, Ark. Gainesville, Fla. Homestead, Fla. Quincy, Fla. Sanford, Fla. Experiment, Ga. M a n h a t t a n , Kans. Lincoln, Nebr. Berkeley, Calif. Davis, Calif. Lind, Wash.	
Prairie		Ames, Iowa		St. Paul, Minn. Urbana, Ill. Lafayette, Ind.
Chestnut or Brown	Bozeman, Mont.	Miles City, Mont.		Fort Collins, Colo. Hesperus, Colo. Logan, Utah. Litchfield Park, Ariz. Bard, Calif. Chico, Calif. Lubbock, Tex.
Reddish Chestnut, Reddish Brown, Red Desert, or Noncalic Brown.		Mesa, Ariz. Ysleta, Tex.	Weslaco, Tex. Sacaton, Ariz. Tucson, Ariz. Yuma, Ariz. Indio, Calif. Riverside, Calif. Shafter, Calif. Albuquerque, N. Mex. State College, N. Mex.	
Organic soils: Red and Yellow Podzolic.	Belle Glade, Fla.	Canal Point, Fla.		

SPRING 1943

Mineral soils: Podzol		Sturgeon Bay, Wis.		Ashland, Wis.
Brown Podzolic	Burlington, Vt.	Bonnors Ferry, Idaho.	Bonnors Ferry, Idaho.	Burlington, Vt. Bonnors Ferry, Idaho Windsor, Conn. Paramus, N. J. W. Junis, N. Y. Luce, Mich. Alicia, Mich. Seneca Falls, N. Y. New Brunswick, N. J. Blacksburg, Va. Wooster, Ohio. Corvallis, Oreg. College Station, Tex.
Gray-Brown Pod- zolic.	Geneva, N. Y.	W. Junius, N. Y. Big Flats, N. Y. East Lansing, Mich. Madison, Wis.	W. Junius, N. Y. Luce, Mich.	
Red and Yellow Pod- zolic.				Denton, Tex. Stewart, Minn. Urbana, Ill. Ames, Iowa Columbia, Mo. Lincoln, Nebr. Stillwater, Okla.
Prairie		St. Paul, Minn. M a n h a t t a n , Kans.		

TABLE 1.—*Results of kok-saghyz plantings made in 1942-43, by soil types and localities—Continued*

SPRING 1943—Continued

Soil region	Satisfactory results		Unsatisfactory results	
	Good	Fair	Poor	Failure
Chernozem.....	Red River Valley, Minn.	Red River Valley, Minn. Edgeley, N. Dak. Langdon, N. Dak. Park River, N. Dak.	Red River Valley, Minn. Chaffee, N. Dak. Fargo, N. Dak. Brookings, S. Dak.	Red River Valley, Minn.
Chestnut or Brown.....	Missoula, Mont.	Missoula, Mont. Miles City, Mont. Klamath Falls, Oreg. Bozeman, Mont.	Missoula, Mont. Logan, Utah Laramie, Wyo. Pullman, Wash.	Lind, Wash. Klamath Falls, Oreg. Lewistown, Mont.
Reddish Chestnut, Reddish Brown, Red Desert, or Noncalcie Brown. Organic soils: Podzol.			Riverside, Calif. Ysleta, Tex.	Indio, Calif. Lubbock, Tex.
Gray-Brown Podzolic.	Plainfield, Wis. Geneva, N. Y. East Lansing, Mich. Excelsior, Minn. McGuffey, Ohio.	Aitkin, Minn. Alicia, Mich. Madison, Wis.	Aitkin, Minn. Alicia, Mich.	Aitkin, Minn. Alicia, Mich. Coddington, Wis. Seneca Falls, N. Y. Walkerton, Ind.
Prairie.....				Crystal Lake, Iowa.
Chestnut or Brown.....		Klamath Falls, Oreg.	Klamath Falls, Oreg.	Klamath Falls, Oreg.

FALL 1943

Mineral soils: Gray-Brown Podzolic.	Geneva, N. Y. W. Junius, N. Y.	East Lansing, Mich.		
Red and Yellow Podzolic.				Napoleonville, La. Beeville, Tex.
Prairie.....	St. Paul, Minn.			
Chernozem.....	Red River Valley, Minn.			
Chestnut or Brown.....	Klamath Falls, Oreg. Missoula, Mont. Edinburg, Tex. Indio, Calif.		Bozeman, Mont.	
Reddish Chestnut, Reddish Brown, Red Desert, or Noncalcie Brown. Organic soils: Podzol.		Winter Haven, Tex. San Mateo, Calif. Glendale, Ariz.	Bakersfield, Calif. Salinas, Calif.	
Gray-Brown Podzolic.	Aitkin, Minn.			Geneva, N. Y. East Lansing, Mich.
Red and Yellow Podzolic.	Belle Glade, Fla.	Canal Point, Fla.		

The specific soil profile characteristics essential for satisfactory production of kok-saghyz as revealed by field observations and analyses of 360 soil samples collected from many fields and plots are, according to Lyford (26*p*), as follows.

Relief

The character of the relief on which the soils occur within any area is important in determining the acreage that can be used for grow-

ing kok-saghyz. Experience has indicated that seeds, seedlings, or even the plants up to a month or 6 weeks of age may be destroyed or seriously injured by heavy rains. Even though the surface of the soil is level the shallowly planted ($\frac{1}{4}$ - $\frac{1}{2}$ inch) seeds may be washed out by the impact of the raindrops or by relatively slight movement of the surface water that has accumulated. In many places rains of high intensity cause sufficient compaction of the surface soil so that seedling emergence is hindered or entirely prevented. This condition appears to be particularly true on soils relatively low in organic matter.

If the land has an appreciable slope considerable damage from the run-off occurs. In depressions plants may be smothered by sedimentation. Only soils which occur where the surface has less than about a two percent gradient are considered suitable unless strip cropping is used to minimize the danger from running water.

It may be feasible to grow the plant on relatively long slopes up to 5 percent in those areas of the Chernozem and possibly the Prairie region which are climatically adapted, especially on those well-managed fields where the high content of organic matter and good granulation that characterize virgin soils remain. On such soils water is absorbed relatively rapidly and washing may not be serious.

TABLE 2.—*Soil characteristics and crop history of lands used for kok-saghyz plantings, 1943-44*

Location and owner	Acres	General soil type	pH	Previous crop history	Remarks
Minnesota:					
Moorhead:					
Bekkerus, G.	12.16	Bearden loam	7.4 to 8.2	Corn, potatoes, grain, onions, beets	Good moisture-holding soil.
Stokness, O.	32.82	do	7.4 to 8.2	do	Do.
Grover, O. R.	19.90	do	7.4 to 8.2	do	Do.
Lamb, J. T.	25.00	do	7.4 to 8.2	do	Poorly drained in part.
Stokness, A.	58.80	do	7.4 to 8.2	do	Good moisture-holding soil.
Crookston:					Good moisture-holding soil.
Thuren, A.	40.00	Bearden silt loam	7.3 to 7.6	Potatoes, small grain	Good moisture-holding soil.
Thuren, T.	28.79	do	7.3 to 7.6	do	Good moisture-holding soil.
Ross, Arthur	30.00	do	7.3 to 7.6	Sugar beets, small grain	Do.
Wagner, L.	20.00	do	7.3 to 7.6	Potatoes, corn, small grain	Do.
Woodstrom, C. P.	40.00	do	7.3 to 7.6	Potatoes	Subject to flooding from Little Willow River—15.6 acres poorly drained.
Aitkin:					Poorly drained.
Gleason, M.	53.00	"Subdued" peat	5.4	Part in flax in 1941 only	Somewhat drier than other 2 tracts. Lime 1.18 to 1.38.
State of Minnesota	40.00	"Wild" peat	4.6 to 4.8	Flax in 1942 only	Some
Stapp	12.50	Partly subdued peat	4.5 to 4.7		
Stewart:					
Russ, Wm.	12.00	Webster silty clay loam	7.2	Corn, grain	Somewhat heavy for good production in a wet year.
Cass Lake Nursery:					
Forest Service	32.00	Fine sand	4.9 to 5.1	Coniferous tree seedlings	
Wisconsin:					
Plainfield:					
Woodward, H. L.	40.00				
Saginaw:					
Farm Security Adminis-	100.00	Carlisle muck; Clyde clay loam, mucky phase.	6.8 to 7.5	Sugar beets, corn, grain, cucumbers	
tration.		Wausson fine sandy loam; Brookston loam; Allendale loamy fine sand.	6.0 to 7.2	Beans, grain, corn	Soil probably not properly classified as to Brookston loam.
Eisenhauer, A.	25.00				
Manistique:					
Forest Service	20.00	Rubicon fine sand	4.9 to 5.1	Coniferous tree seedlings	
Montana:					
Missoula:					Irrigated.
Coster, R.	8.33	Brown silt loam	(1)	Garden tract, potatoes, alfalfa, grain	Do.
Hahn, H. T.	14.41	do	(1)	do	Do.
Turi, S.	5.20	do	(1)	do	Do.
O'Laughlin, E.	5.00	do	(1)	do	Do.
McCauley, C.	18.00	do	(1)	do	Do.

Frenchtown: Lelselt, V. E.	9.15	4.15 acres sandy silt loam: 5.0 acres gray silt loam.	(¹)	Grain, sugar beets, peas, alfalfa	Do.
Lewistown: Peterson, C. J.	1.00	Sandy loam	(¹)	Grain	Dry farm.
Sawac: Forest Service	1.00	Floury silt of glacial origin	(¹)	Coniferous tree seedlings	Irrigated.
Miles City: Bureau of Animal Indus- try.	3.00				Do.
Idaho: Bonners Ferry:					
Oregon: Bauman, S. M.	1.00	Gray silt loam	(¹)	Grain, alfalfa	Dry farm.
Klamath Falls: Worden	40.00	Well decomposed peat			
Bureau of Reclamation	29.00	Fine sandy loam	7.0 to 8.0 9.06	Small grains Wild land	Irrigated from below. Low in organic matter. Irrigated.
Vermont: Burlington:					
Valado	9.80	Sudbury fine sandy loam	6.8	Sod previous 3 years	
New York: Seneca Falls:					
Rogers	11.00	Ontario loam	6.0	Soy beans 1942, beans 1941, sod 1940	Rather stony.
Pease	14.00	Ontario loamy fine sand	5.5 to 6.0	Clover 1942, rye 1941, sweet corn 1940	"Droughty," up to 15 percent slopes.
Fish and Wildlife Service	40.00	Carlisle muck		Potatoes 1942, weeds 1941, peppermint 1940.	
Florida: Belle Glade:					
VanLandingham	20.00	Saw grass peat	5.9 to 6.2	Potatoes 1941-42, Escarole 1942-43	Subirrigated when necessary.
Louisiana: Napoleonville:					
Milkin and Farwell	5.00	Yazoo fine sandy loam	6.2	Sugar cane 3 previous years	Soil crusts badly.
California: Salinas:					
Guayule lease	1.00	Hanford sandy loam	6.8 to 7.7	Guayule 2 years, vegetables	Low in organic matter. Irrigated.
Bakersfield:					
Guayule lease	2.50	Arvin loamy fine sand	7.0	Fallow 1943, cotton and alfalfa	Do.
San Clements:					
Bureau of Plant Industry	5.00	Salinas fine sandy loam	7.0	Guayule 1 year, navy beans 2 years	Do.
Arizona: Phoenix:					
Guayule lease	2.50	Gila silty clay loam	(¹)	Fallow 1943, cauliflower 1942-43, maize 1942.	Calcareous. Low in organic matter. Ir- rigated.
Texas: Edinburg:					
Guayule lease	2.50	Willacy fine sandy loam	8.2	Fallow 1943, oats and rye 1942, sesbani 1941.	Noncalcareous. Low in organic matter. Irrigated.

¹ pH not known.

A 10-acre planting made in the spring of 1943 in the Prairie region at Stewart, Minn., on Clarion silt loam and Webster silty clay loam, representative of large acreages in this region, was a complete failure. After a 3- to 4-inch rain which occurred while the plants were in the seedling stage, the soil lost its desirable loose granular condition and became too hard to work. Subsequent growth was poor and management of the field was difficult.

Seemingly level areas in many places, however, may not be altogether suitable because they include small depressions in which poorly drained soils occur. Not only is growth unsatisfactory in these poorly or imperfectly drained areas but cultural operations are made difficult because these depressions must be avoided.

Texture

Kok-saghyz appears to tolerate a rather wide range of soil textures, provided the other soil characteristics are favorable. Good growth has been obtained where the surface and subsoils range in texture from loamy sand to silty clay. The greatest uniformity of good growth and the most satisfactory results from the standpoint of management were obtained on the surface and subsoils ranging in texture from loam to silty clay loam.

Soils which are fairly light textured throughout, that is, ranging from loamy coarse sand to fine sandy loam, are most desirable from the standpoint of workability although they may be subject to drought and soil blowing, and are usually less fertile than heavier textured soils. However, if the surface soil is light textured but is underlain by a clay layer, or the permanent water table at about 30 to 40 inches, the moisture relations may be satisfactory. Under such conditions Melrose fine sandy loam and Sudbury loamy sand at Burlington, Vt., gave consistently good results. In selecting soils that have an impervious layer close to the surface care should be used because there may be poor drainage in humid regions and in the drier regions poor drainage and salt accumulation.

In humid regions soils at the other extreme of texture, in the range from silty clay loam to clays, are generally favorable from the standpoint of moisture availability but tend to become compact and to bake and crust. In regions of lower rainfall these soils are not generally favorable.

Difficulties were experienced in harvesting roots in the fall from heavy textured soils. Spring 1944 harvesting operations in the Red River Valley of Minnesota indicate that roots can be harvested with less difficulty after freezing and thawing have loosened the soil and promoted granulation.

There are also indications that in medium to heavy textured soils roots are distorted and the penetration of lower roots limited or to some degree inhibited.

Reaction

In general, most satisfactory growth of kok-saghyz was obtained on those soils within a pH range of 5.5 to 8.5, and there was some indication that growth was consistently better if the pH was above 6.5.

Good growth was not obtained on any mineral soil examined in detail where the surface soil had a pH lower than 3.6. However, only fair growth was obtained on one type, Unadilla very fine sandy loam, the surface soil of which had a pH of 5.3. Also, germination did not take place at all on an area of Dunkirk silt loam, which had a surface pH of 4.9.

On organic soils good growth was obtained where the pH of the surface was as low as 5.4. Growth on one field of Rifle peat with a surface pH of 5.2 was only fair. In another field of Rifle peat roots grew well in an underlying horizon which had a pH of 5.2. Here the pH of the surface was about 5.5. A failure resulted on a third field of Rifle peat where the pH of the surface soil was 4.9.

Unless the supply of available calcium in a soil is known to be high it would probably be unwise to select for kok-saghyz production any soil, mineral or organic, where the pH is below 5.5. No doubt even at this pH it would be advisable to use lime in addition to the regular fertilizers.

Where the surface soil had a pH range of 8.5 to 9.3 satisfactory growth resulted if the underlying horizons were permeable and had good drainage and less than 0.2 percent of soluble salts. For instance, at Klamath Falls, Oreg., on Spring Lake loamy fine sand, fairly satisfactory growth occurred where the surface soil to a depth of 13 inches had a pH of 9.0 and where the underlying horizons were more alkaline. In this instance the percentage of soluble salts in all horizons was below 0.14 and the soil was permeable throughout. Where the pH of the surface was above 9.3 growth was not satisfactory.

Organic Matter

Kok-saghyz can be grown on soils that range from as low as 2 percent to as much as 90 percent of organic matter. Good results have been obtained on peats, on mucks, on mucky phases of mineral soils, and on mineral soils that range in organic matter content from about 2 to 8 percent.

The beneficial effect of organic matter appears to result primarily from the physical properties imparted to the soil. Organic matter tends to promote granulation and increases moisture holding capacity, the rate of percolation, and the amount of total pore space.

Permeability

The best growth of kok-saghyz occurs where the soil is fairly permeable. With the exception of conditions under which the water table is held at a depth of about 30 to 40 inches by an underlying impervious layer, hard or compact layers or layers impervious to water within the upper 30 to 36 inches usually cause unsuitable conditions in the soil profile. Hard upper subsoil layers develop in some soils when dry conditions prevail and as a result the roots are prevented from growing downward and are forced to grow along the interface between the surface and subsoil. These conditions were observed particularly on Todd loamy sand at Cass Lake, Minn., and on Ottawa loamy fine sand at West Junius, N. Y. Actual distortion of the main taproot was observed in Peone silty clay at Bonners Ferry, Idaho.

Moisture

For optimum growth an adequate, but not excessive, supply of moisture must be present in the soil at all times. The surface and subsoil should have good water holding capacity and should be well but not excessively drained. The permanent water table should be below 30 inches and porous sand or gravelly layers should not be present within about 3 feet of the surface.

If porous sand or gravel occur within the upper part of the profile the soil is likely to be subject to drought, even in relatively short periods of dry weather, because there is not sufficient moisture holding capacity above the porous layers. The detrimental effects of shallow gravelly layers on the moisture relations was especially noted at Missoula, Mont., on the Moiese soils. Here the depth of the silt loam surface and subsoil was variable over gravel, and the smaller growth on those areas where the gravel was close to the surface could readily be observed.

Soluble Salts and Alkalies

No detrimental effects were noticed when the concentration of soluble salts (salts other than sodium carbonate) was less than 0.1 percent. Larger quantities of soluble salts occurred only on the fields in the vicinity of Klamath Falls, Oreg. In this area their effects were complicated by the presence of alkali (sodium carbonate). All indications point to the fact that kok-saghyz is similar to many other agriculture crops in respect to soluble salts in that growth is not satisfactory where the amount in the soil is much greater than 0.2 percent.

Not much was known in 1942 about the requirements of the plant and its particular characteristics. One factor given considerable

weight in locating early test plantings was the existence of relatively large areas of the soil type being tested to assure the possibility of expansion in the event the soil proved adaptable and an enlarged program of rubber production was determined upon.

Because of some fear that kok-saghyz might become a farm pest, Forest Service nursery areas relatively distant from farm areas were chosen for the first large scale test plantings. The soils in these nurseries varied from fine sand to fine sandy loam. These soils had been kept well fertilized for the production of coniferous trees by the annual addition of peat plus mineral fertilizer (as 1- to 2-year old compost), but they did not prove to be highly productive of kok-saghyz. Not only were they not properly fertilized for kok-saghyz production but they required heavy and frequent applications of water through overhead watering systems.

All of the 1942 Montana sowings were irrigated as required (5p). The best stand was secured at Savenac Nursery but because of soil conditions and the colder climate due to the higher elevation the plants did not develop well. The soil at two other locations was much better but a heavy rain followed by hot weather resulted in soil crusting prior to germination and the tiny plants could not break through the crust. Moreover, it is now known that the $\frac{1}{2}$ -inch depth of sowing was too deep and the amount of seed per acre (from 0.1 to 1.0 pound) was much too light. Seven acres were abandoned at Miles City and $14\frac{1}{2}$ acres at Missoula because of the exceedingly light stands.

Temperature

Summer

No records of Russian experiments to determine the effect of temperature on the growth and productivity of kok-saghyz were available at the time investigations were begun in this country. However, the temperature of the native habitat of the plant would suggest the Northern States and Canada as more suitable for its growth than warmer areas. Accordingly, more attention was devoted to testing this area, although indicator plantings were made over all of the United States to determine the plant's range of adaptability.

The lack of complete tabulations of temperature data makes it impossible to arrive at conclusions regarding specific mean, maximum, or minimum temperatures associated with most satisfactory kok-saghyz production. Temperature data reported for spring-summer plantings of 1942 and 1943 are shown in table 3, and some data for two winter test locations are given in table 4.

TABLE 3.—Average maximum, minimum, and mean temperatures for the months June to September 1942 and 1943 at kok-saghyz test locations in the United States

Location	1942											
	Maximum				Mean				Minimum			
	June	July	Aug.	Sept.	June	July	Aug.	Sept.	June	July	Aug.	Sept.
Geneva, N. Y.	79.9	84.1	81.5	74.7	-----	-----	-----	-----	56.9	60.7	57.6	51.4
Lancaster, Pa.	81.0	84.3	80.6	78.1	-----	-----	-----	-----	60.6	63.9	61.5	54.7
Burlington, Vt.	74.0	77.8	76.1	-----	65.1	68.4	66.6	-----	56.2	58.9	57.2	-----
St. Paul, Minn.	74.4	80.9	80.2	65.9	-----	-----	-----	-----	57.9	61.6	61.0	49.1
Brookings, S. Dak.	79.3	83.2	82.5	-----	-----	-----	-----	-----	54.1	57.9	57.8	-----
Madison, Wis.	-----	-----	-----	-----	67.0	71.8	70.1	60.0	-----	-----	-----	-----
Urbana, Ill.	-----	-----	-----	-----	73.1	79.5	74.5	66.1	-----	-----	-----	-----
Ames, Iowa	79.4	84.2	82.2	-----	69.4	73.6	60.7	-----	59.5	62.9	-----	-----
Manhattan, Kans.	83.7	92.6	88.0	77.7	-----	-----	-----	-----	63.8	69.1	67.4	56.5
Wooster, Ohio	78.5	83.0	-----	-----	-----	-----	-----	-----	57.4	60.0	-----	-----
Parma, Idaho	-----	-----	88.2	79.3	-----	-----	-----	-----	-----	-----	51.0	42.3
Laramie, Wyo.	69.0	79.2	77.5	65.8	-----	-----	-----	-----	43.5	51.8	49.8	39.1
Capistrano, Calif.	173.0	173.0	75.0	74.5	-----	-----	-----	-----	155.0	155.0	60.0	55.0
Riverside, Calif.	192.0	192.0	95.0	90.0	-----	-----	-----	-----	155.0	155.0	57.0	52.0
Pullman, Wash.	65.6	81.1	81.7	71.9	-----	-----	-----	-----	47.2	55.6	55.8	48.7
Toppenish, Wash.	76.6	90.5	91.6	84.3	-----	-----	-----	-----	46.0	53.5	51.8	46.2

Location	1943											
	Maximum				Mean				Minimum			
	June	July	Aug.	Sept.	June	July	Aug.	Sept.	June	July	Aug.	Sept.
Geneva, N. Y.	85.1	85.6	82.1	76.6	-----	-----	-----	-----	60.9	61.3	58.9	51.3
Burlington, Vt.	77.7	81.4	77.0	68.8	67.2	70.3	67.5	58.3	56.7	59.2	58.0	47.9
East Lansing, Mich.	79.0	80.7	77.9	67.5	-----	-----	-----	-----	60.1	70.4	59.4	47.5
St. Paul, Minn.	77.5	84.2	81.3	67.7	-----	-----	-----	-----	60.9	63.5	61.6	46.2
Brookings, S. Dak.	79.0	86.3	83.2	70.3	-----	-----	-----	-----	56.0	59.8	59.3	44.8
Madison, Wis.	77.4	82.7	80.5	66.2	69.4	74.0	71.8	58.2	61.3	65.4	63.2	50.2
Manhattan, Kans.	85.3	90.7	95.7	80.9	75.7	79.5	83.4	67.6	66.1	68.3	71.2	54.3
Bozeman, Mont.	66.0	79.1	79.3	72.1	-----	-----	-----	-----	42.0	49.5	48.3	40.4

1 Only 1 figure reported for June and July.

2 Through Sept. 13 only.

TABLE 4.—Average maximum and minimum temperatures during certain winter months of two southern fall-winter planting locations

Location	Month	Temperature	
		Maximum	Minimum
Tuscon, Ariz.	October 1942	82.3	51.3
	November 1942	77.3	41.8
	December 1942	67.8	34.8
Belle Glade, Fla.	January 1944	73.9	50.3
	February 1944	82.0	52.9
	March 1944	82.9	58.3
	April 1944	81.9	61.1

The fact that best results have been attained in the northern third of the United States and in southern Canada suggest that the plant grows better where average daily temperatures are not too high, where very high day temperatures do not remain for continued long periods, and where nights are usually moderately cool. Occasional high temperatures apparently are less objectionable than slightly lower but more constant high temperatures. Actually, higher maximum temperatures are sometimes reached in Minnesota and other Northern States than in some locations farther south but the duration of the periods of

high temperatures is usually relatively short. Much lower temperatures are the rule.

Prolonged high temperatures had serious deleterious effects on the majority of kok-saghyz plantings in the South or Southwest whether spring or fall planted. Harvest of the crop before high temperatures occur is essential and in most trials growth was not sufficiently advanced at the advent of hot weather to insure reasonable yields of roots and good rubber content.

The injurious effects of high temperatures may come about either directly by outright killing of the plants, particularly in the earlier stages of development, or indirectly by hastening "summer dormancy." In the latter condition the plants are weak and are easily attacked by pathogenic organisms which may cause serious damage. Numerous cooperators in low rainfall or irrigated areas reported adverse effects of high summer temperatures both in 1942 and in 1943 on seedlings or younger plants. Information from controlled experiments on the relationship of temperature to growth is limited but indicates that relatively lower average growing temperatures, particularly when associated with long days, favor best development of kok-saghyz. Thus, unpublished data from preliminary trials of R. H. Roberts³ at Madison, Wis., suggest better plant size and somewhat higher rubber content when kok-saghyz was grown at 55° F. continuously, or alternating 55° F. night and 75° F. day temperatures, than when grown at 75° F. continuously. Borthwick, Parker, and Scully (11) found cool temperatures and long photoperiods most favorable to early blooming of kok-saghyz seedlings.

Kok-saghyz has done well as a summer crop in western Ohio and in central Iowa although the rubber content was not quite as high as farther north. The region north of the Corn Belt proper, that is in the spring wheat, hay, and pasture region, affords a climate which is well suited for the growing of kok-saghyz as a summer crop.

Winter

In the South the minimum temperature appears to be the principal controlling factor in limiting the areas where kok-saghyz can be successfully produced in the winter period. Experience indicates that where the temperature falls below 25° F. for two or more consecutive days or below 20° F. at any time during the very early life of the plant it cannot survive. It also appears doubtful that satisfactory growth will occur where the mean temperature is less than 50°-55° F.

³ Roberts, R. H., unpublished data from greenhouse experiments on the influence of photoperiod and temperature on growth and development of kok-saghyz at Madison, Wis., in 1942-43.

Winter temperatures, therefore, limit the production of kok-saghyz as an overwinter crop to Florida, Texas, Arizona, and California, with a possibility that the extreme southern portions of Louisiana, Mississippi, Alabama, and Georgia might be suitable (8*p*).

Another aspect of the operation of temperature as a limiting factor was reflected in experience with Minnesota plantings in the spring of 1944 (2*p*). In general, April and May of 1943 were slightly colder than normal but June and July were somewhat warmer. The fall of 1943 was favorable to growth, and root volume increased rapidly in the last month of the growing season. Unseasonable late spring or early fall frost did not occur in 1943, but a severe freeze with a temperature of 20° to 25° F. was experienced in the Red River Valley in early May 1944. This freeze killed early-germinated kok-saghyz seedlings.

Snow cover appears to be of considerable importance in successful establishment and carry-over of fall and winter plantings where temperatures much below freezing occur. Under some conditions it may be of importance even with carry-over of plantings made the previous spring. In general, the northern part of the United States considered most favorable to kok-saghyz culture corresponds fairly well to that part having an annual average of 80 or more days with more than 1-inch snow cover. Snow cover may actually have no direct bearing on the location of the most favorable zone of production but might be important for plantings carried beyond the first year.

In the majority of locations far south of this most favorable zone, with average annual minimum temperatures much below 15° F., attempts to carry fall plantings of kok-saghyz through the winter have been generally unsuccessful. Such losses of plants were due in some cases to actual low temperature injury or killing, in others to frost heaving where successive freezing and thawing caused the roots to be broken off or pushed out of the soil. Micro-organisms, entering at the points where the root breaks occurred, often caused serious rotting and loss of plants. Even in the northern area serious injury or heaving may occur during periods of open weather when snow cover is inadequate and there is alternate freezing and thawing.

The extent of injury may be more serious on certain organic soils than on mineral soils in the same area. An extreme case of root heaving (fig. 5) was encountered on muck soil near Geneva, N. Y., (56*p*) during the winter of 1943-44. No such heaving was observed on an adjacent well-drained sandy to silty loam mineral soil even though snow cover had been less and temperatures higher than normal that winter.

Relatively little winter loss was observed in 1943 over the greater part of the most promising growing area. However, serious cold



FIGURE 5.—Results of winter heaving of kok-saghyz plants on muck soil at Geneva, N. Y., 1943-44. (Bureau of Plant Industry, Soils, and Agricultural Engineering.)

injury to 1942 plantings was reported from Storrs, Conn., and Lancaster, Pa.

In the test areas in the South, the winter of 1943-44 was somewhat drier and colder than usual. Kok-saghyz seems to require warm days and cool nights for best growth and development. Since these conditions did not exist during December, January, and February, development was slow. This delayed flowering and seed production, except in the Texas and Florida areas, to such an extent as to question

whether overwinter production of seed can be accomplished in time to send the seed north for planting the same season.

Moisture

Russian reports indicate that in the wild kok-saghyz is found in regions with relatively high soil moisture. The Russians also found that, within limits, dry weight of the plant and rubber content are directly related to the availability of water, and they reported further that the period of greatest water requirement is from germination to time of flowering (22, 24, 67). The general recommendation of the Russian publications is that areas with sufficient rainfall to grow satisfactory vegetable crops are adaptable to kok-saghyz cultivation.

These findings, together with studies of precipitation data and weather maps, suggest that for proper culture of kok-saghyz in the northern part of the United States, where irrigation is not practiced, the annual precipitation must be 20 inches or more. At least 15 inches should occur during the growing season of April to September with approximately 8 inches during June to August. Reasonably well-distributed precipitation, rather than sporadic heavy rains, is necessary, especially during the germination and small-seedling stages.

Under irrigated conditions uniform and adequate moisture must be supplied during the early growth stages if satisfactory germination, stands, and growth are to be attained; factors other than moisture supply, though, are more likely to favor or limit the production of kok-saghyz.

In the southern and southeastern parts of this country rainfall will usually be adequate for winter production.

A single test planting at College, Alaska, in 1942, was largely a failure because of a scarcity of rainfall at planting time although subsequent growth of the few surviving plants was fairly good.

The years 1942, 1943, and 1944 up to June 30 were considered to be within a wet cycle, yet on the whole the yearlong average precipitation varied little from the long period average. On the other hand, the distribution of precipitation was such as to interfere seriously with farming operations. In the spring of 1943 in the Red River Valley of Minnesota early spring rains and melting snows on the watershed above Moorhead produced one of the highest floods on record. Some fields were inundated and many were so saturated they were slow in drying out. Only a few fields were in a condition to be prepared and sown in late April and early May. Heavy rains at intervals interfered with ground preparation and sowing and prevented early cultivation and weeding. Some reseedling was required because of weeds.

Soils at Moorhead, Minn., dried out earlier than those at Crookston. But on the whole, sowing was not done any earlier than in 1942 when

the first seed from Russia did not reach the field until mid-June. A similar situation existed at Aitkin. Here the soil was in a satisfactory condition about the middle of May but later heavy rains on the Mississippi watershed flooded the peat soils.

At Stewart, Minn., ground preparation and sowing were done in late April, but the soil became so dry as to prevent good germination until after a rain on May 6. Heavy rainfall, starting on May 15 and continuing at frequent intervals for a thirty day period, prevented all cultivation and weeding. During this period weeds flourished and suppressed the kok-saghyz to such an extent that it did not recover. Most of this field was reseeded in June but growth was not good and the field was abandoned in September.

Early and frequent rains in Michigan in the spring of 1943 delayed sowing until June. The mineral soil proved to be a poorly drained phase of the soil type selected, cultivating and weeding were difficult, and growth was poor.

Excessive rains in late April and early May interfered seriously with the 1943 operations in New York. Sowing was not accomplished on the mineral soil until early June for the sandy loam field and mid-June for the Ontario loam field. The peat area was under water during most of May and did not dry out enough to allow working until the latter part of June. Sowing was done on June 30 and July 1. Immediately following the sowing a period of extreme heat and drought occurred and the seed failed to germinate.

In Montana and Oregon the spring of 1943 was 2 to 3 weeks late, and colder and drier than usual. In Montana sugar-beet growers figured that the growing season was 20 days shorter than normal. This short season resulted in a considerable reduction of beets per acre and it may well have had a similar effect on the kok-saghyz root production. Intermittent spring rains delayed ground preparation and seeding operations in the Missoula Valley. The fall season was without snow or severe weather. At Miles City, east of the Continental Divide, the season as a whole was favorable. Here the lighter soils dried out more rapidly so that there was little interference with cultural operations.

During the spring of 1944 excessively heavy rains in June interfered seriously with sampling and eradication operations at Missoula. Eradication was finally accomplished but under wet soil conditions that frequently bogged down the tractor. As a result of the heavy rains in June 1944 a large proportion of the second year seed crop was lost.

The climatic range of kok-saghyz appears to be the northern States from Vermont west to eastern North Dakota and South Dakota. Summer droughts sometimes occur within this area, but only in the

Red River Valley in western Minnesota and eastern North Dakota and South Dakota is there any real risk that the precipitation may not be sufficient to permit germination and good growth. Weather records over a period of 36 years suggest that one crop out of every five might be poor in that region because of low rainfall. Portions of the area received less than 16 inches during the crop season 8 times in the 36 years, but only in 1933 and 1934 did this happen in consecutive years.

The 1943 production tests in Montana and Idaho, as well as numerous adaptation tests elsewhere in the drier West, indicate that it is not advisable to attempt dry farming of kok-saghyz on areas west of the Red River Valley. But if abundant water is available for irrigation, kok-saghyz will grow and thrive wherever soil and temperature conditions are favorable.

Excessive drying out of the soil, along with high temperatures, usually causes the plants to become dormant, or lengthens the dormant period, with resultant loss of growth, and may even cause death of the plants. On the other hand, excessive precipitation during the growing season interferes with seed collection and reduces the seed harvest. On many soils it adds materially to the difficulties and cost of cultivating and weeding. Late fall or early spring should be comparatively dry to facilitate root harvesting, particularly on the heavier soils. Nonetheless, there must be moisture in the soil in the spring to secure satisfactory germination. Temperature and rainfall lines have been given by Lyford (26*p*).

Kok-saghyz does not tolerate excessive moisture during its early growth period. After the plant is well established it survives standing water as well as most cultivated crops, but it seldom recovers if flooded for more than a day or two during the growing season. Kok-saghyz is not more exacting in moisture relationships than other vegetable or root crops.

Length of Growing Season

Available Russian reports contain no data bearing directly upon the relation between length of growing season and satisfactory growth and production of rubber and seed of kok-saghyz. Inasmuch as most of the test plots and experimental areas on which kok-saghyz was grown in this country were within the same general range no significant leads on the effect of different lengths of growing season have been obtained.

However, certain pertinent observations on experimental work carried on in this country are recorded in connection with the discussion of the effects of time of sowing and time of harvest.

Disease, Insect, and Other Biological Factors

While the publications of Russian investigators contain few references to the biological factors involved in the selection of planting areas for kok-saghyz, it is obvious that certain of them are of the utmost importance.

The plant is insect-pollinated. Experience in the Minnesota, Montana, and Oregon plantings demonstrated clearly the need for adequate insect populations to insure maximum pollination. Whether root size and rubber production as well as seed yield are related to fertilization is not known. Fields which set little seed showed no significant deviation from the general average of root and rubber production.

At least on certain soils, the presence or absence of soil-conditioning organisms is a matter of importance.

The necessity for avoiding areas known to be infected or infested with injurious organisms was illustrated by the wiping out of one test planting at Ithaca, N. Y., by root-rot organisms held over in the soil from earlier plantings of cabbage, and by the destruction of several other plots by leafhoppers and grasshoppers. Some of the plantings in Florida were made on peat areas with heavy infestations of cutworms. About 80 percent of these stands were destroyed.

Economic and Other Factors

Rubber is extracted from kok-saghyz by a mill operation. Since this is so, economical production demands plantings of sufficient acreage within relatively short distances of a mill. Transportation of roots to the mill requires adequate railway and highway facilities.

Any region chosen must contain areas of satisfactory land large enough to permit selection of acreages of sufficient size to produce enough roots for year-long mill operation. The displacement of other crops and the various relations of kok-saghyz to the production of other crops must also be considered.

Both Russian and American experience has indicated that the growing of kok-saghyz requires a large amount of labor. Consideration of any areas requires careful examination of the availability of qualified labor.

CULTURAL PRACTICES

Seed Testing and Seed Treatment

Kok-saghyz germination studies made by A. B. Kiselevoy and reported by Poptsov (51) in 1932 indicate the existence of dormancy and of very slow and frequently aberrant germination. When a systematic study of the plant and its cultivation was begun in Russia in

1933, special attention was given to the problems of germination and development of methods of securing a high percentage of rapid, uniform, and otherwise satisfactory germination. These investigations revealed the relation of temperature, moisture, and several other factors to germination and led to the development of storage methods and various presowing treatments.

The Russian seed received in this country in May 1942 was not accompanied by data indicating its origin, time of collection, degree of purity, percentage of germination, or even whether it had been collected from plantings or the wild; nor was this information obtainable.

In order to obtain basic data on viability, purity, and behavior, adequate samples of the seed were tested. In such tests at the Lake States Forest Experiment Station, St. Paul, Minn., in May 1942, Roe (34*p*) found that the germination of dry seed (not pretreated) sown in sand at a depth of $\frac{1}{8}$ inch averaged only 60 percent of that of similar seed in petri dishes. However, when the seed was stratified for 10 to 30 days at 41° F. or soaked for 24 hours in running tap water at a temperature of 72° F., and then sown in sand, almost all of it germinated.

Seed which had a high moisture content was prechilled at Beltsville for about 15 days at 32° F. and sent to St. Paul in a thermos bottle. It showed practically complete germination when sown in sand. Erroneously this operation was called vernalization by some investigators. Vernalization according to Roe (34*p*) is an entirely different process consisting of chilling seed which previously has been induced to germinate at a higher temperature. Seed, which had been prechilled and then dried before being sent to St. Paul (moisture content when received was about 13 percent), showed little better germination in sand than that which had been sown without pretreatment. Since an examination of the remaining ungerminated seeds showed most of them to be sound and germinable, it seemed probable that the excessive drying had put this seed into a state of secondary dormancy.

Later 1942 tests made on both Russian seed and seed from the first plantings in this country yielded the following significant information. Purity (freedom from dirt, weed seeds, and seeds obviously of rogue dandelions) of Russian seed was high, 94 to 97 percent. Soundness (filled seeds) was also high, 97 to 100 percent. No reliable comparison could be made between purity and soundness of Minnesota and Russian seed since the method of cleaning Russian seed was not known. Minnesota seed (1,217,000 clean seeds per pound of pure seed) compared favorably in size with the average Lysenko (27) gives for Russian seed (1,360,000) although the Russian seed received averaged much larger (940,000). The moisture content of air-dry Russian seed was relatively low, 8.0 to 9.5 percent.

Germination of Minnesota seed and also of Russian seed was high (83 to 94 percent) when sown in petri dishes without pretreatment and when sown in sand following stratification or prechilling. Germination of kok-saghyz seed in sand decreases as the depth of cover is increased. Best results (70 percent) were obtained in the laboratory with $\frac{1}{8}$ -inch cover. A progressive drop occurred from $\frac{3}{16}$ - to $\frac{1}{2}$ -inch cover, while $\frac{3}{4}$ - and 1-inch cover gave no germination at all.

When seed is sown in sand without pretreatment, many seeds lie dormant for several months without germinating. This condition was also found in the field. Observations at the Butternut Nursery, Butternut, Wis., in September 1942 showed many ungerminated seed in sowings made in late May of that year. Of the four germination temperatures tested (68° to 86° F., 50° to 77°, 50° and 41°), 68° to 86° was best for sand tests; but 50° to 77° was practically as good.

Seed to be sown in Minnesota and Wisconsin in 1943 was thoroughly mixed and a composite sample taken for germination tests. At other places samples were taken from each bag and tested separately. Only three samples of the seed to be planted in the Lake States showed a very low germination percentage (34p). A rather high amount of abnormal germination was noticed but it was believed to be due to damping-off organisms rather than any peculiarities of the seed itself.

In addition to the seed to be used in the Lake States, tests were run in early April on samples from six bags of seed to be used at Missoula, Mont., six at Klamath Falls, Oreg., and five at Seneca Falls, N. Y. It was these tests that first brought to attention the extreme variability between lots and the relatively high percentage of abnormal germination.

Hamm (37p) made extensive studies on the temperature relations of germination in kok-saghyz. Germination was most rapid and complete at 23° C. (73.4° F.). An average germination of 81 percent from three 100-seed samples was reached in 5 days. At 17° C. (62.6° F.) an average germination of 48 percent resulted in 6 days. The test was continued for 3 weeks with no increase in germination. At 8° C. (46.4° F.) no germination occurred until the sixth day. Germination was very slow and only reached 16 percent after 3 weeks. Germination at 4° C. (39.2° F.) started on the eleventh day and rose steadily to 35 percent in 2 weeks. Germination was still in progress when the study was terminated.

Temperature studies showed conclusively that the seed had two optimal germinating temperatures, 5° C. (41° F.) and 25° C. (73° F.). Complete germination took place at both these temperatures. At temperatures between 8° C. (46° F.) and 20° C. (68° F.) germination was quite incomplete.

From what is known of the effect of temperature on carbohydrate changes it seems probable that at 25° C. and also at 5° C., in the presence of an ample water supply, there is a conversion from the storage forms of carbohydrates to usable simple sugars. Hamm (37*p*) postulates that at intermediate temperatures the enzyme complex is not in a usable form and little or no germination results. When fruit and seed coats are removed from the seeds, the seeds germinate completely at any of the temperatures tested. If only the fruit coat is removed, germination follows the pattern already outlined. It would seem that the seed coat is the principal cause of incomplete germination at intermediate temperatures and probably the chief cause of a few seed not germinating at any temperature.

In early 1943 tests were made of Russian seed which had been received in 1942. They showed that half the lot had deteriorated to less than 25 percent viability. Check tests in October 1943 showed still further deterioration and all of the old Russian seed showing less than 25 percent germination was destroyed. At the same time the 1942 seed collected at Missoula and in the Lake States showed germination of 84 to 97 percent.

Russian investigators (27, 28, 51, 66) point out that kok-saghyz seed enters dormancy during the after-harvest ripening period, and does not germinate quickly or evenly unless stratified or given other treatment designed to start the biological processes of germination. Lysenko (27) outlines an alternative method of soaking for a few hours followed by partial drying and aeration at room temperature or until the seed shows signs of sprouting, after which it is stored in a cold room until required.

Roe's (34*p*) studies gave results which appeared to favor a treatment consisting of simply soaking the seed for 24 to 48 hours in water and then drying the seed enough to allow it to flow readily through the seed-drill mechanism.

Because of the emphasis placed by the Russians on the prechilling method, instructions were issued in 1943 that seed be prechilled wherever facilities were available. Elsewhere, either Lysenko's method or Roe's simplified method was used.

In all cases after the initial treatment seed was kept in cold storage until sown. Dairy rooms, ice cream plants, etc., were used for the purpose. Temperatures at some of these plants were not under absolute control and some loss was reported by molding and sprouting. Because weather conditions often precluded immediate sowing, it was necessary to hold the pretreated seed for long periods, in some cases in excess of 30 days. Some soaked seed was dried and then reprepared for treatment to reduce probable losses through continued long storage of moist seed.

The difficulties inherent in the management of such seed treatments on any considerable scale by individual growers, or groups of growers, are obvious. Roe's method seems to have the advantage of being the least difficult. Even with this method it is doubtful that refrigeration facilities would be adequate in most cases and the grower would be forced to dry seed not used immediately and resoak it when sowing conditions became favorable.

Zehngraff (45*p*) made a number of studies in connection with pretreatment and aftertreatment storage before sowing and the response in emergence and growth of seed treated by different methods (fig. 6). He reports that seed with a moisture content of 47.2 percent was difficult to hold without damage by molds. Drying to 35 percent moisture content obviated this difficulty under proper refrigeration. He found that after a soaking treatment it was necessary to dry the seed quickly and at fairly low temperatures. Otherwise the seed would sprout and become useless unless planted before the sprouts became too large.

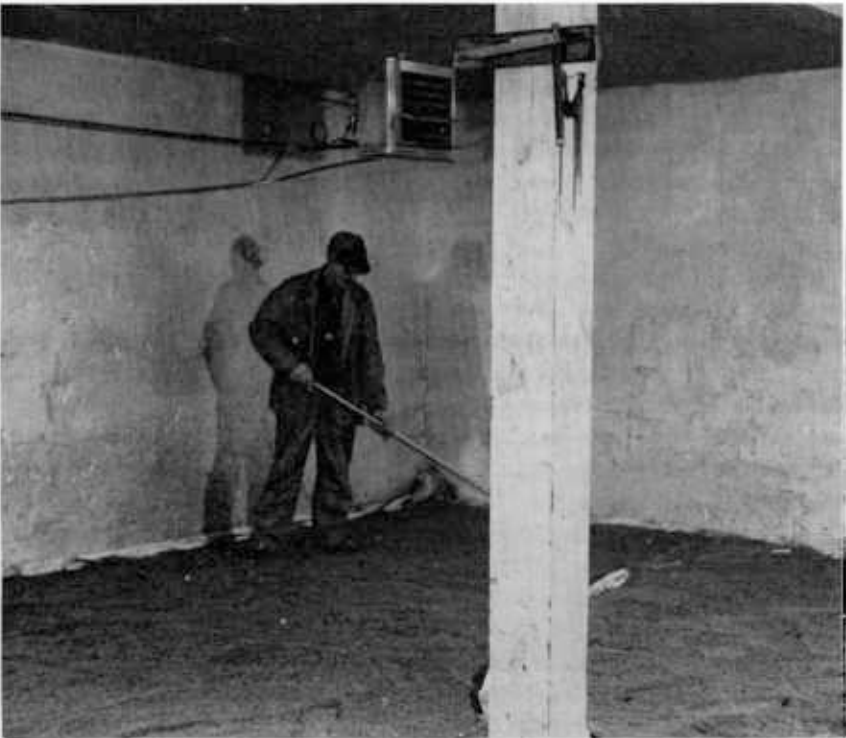


FIGURE 6.—Stirring kok-saghyz seed in cold storage after soaking. (Forest Service—F-426623.)

Hamm (37*p*) developed a method of pretreatment by the use of molecular KNO_3 (potassium nitrate) which gave satisfactory results in the laboratory. Small-plot comparative tests at University Farm, St. Paul, Minn., showed the greatest number of plants from vernalized seed after 2 weeks, but after 2 months there were no significant differences between plants from the KNO_3 treatment, prechilling, or the soak method. However, the development of plants as indicated by the number of flowers at approximately 2 months was decidedly in favor of vernalization or prechilling. The KNO_3 treatment was only slightly better than the soak treatment.

Zehngraff (45*p*) made a comprehensive test on a field scale of the value of different methods of seed treatment. His tests included untreated seed, prechilling, KNO_3 , the Roe method, and what he calls complete vernalization or pregermination. The latter treatment was done by exposing moist or prechilled or soaked seed to slightly below room temperature (60° F.) for two days or until about two percent had actually sprouted, after which it was placed in cold storage (32° to 40° F.) to prevent further germination. After 30 days plantings of pregerminated seed averaged 11.6 plants per linear foot; prechilled, 6.9; Roe method, 3.3; KNO_3 , 0.7; and untreated, 0.2 plants per linear foot.

Zehngraff observed that the difference in emergence is greatest in early spring when the ground is cold. Pregerminated seed is sensitive to dry soil conditions and may fail whereas seed treated in other ways may lie in dry soil several days and still germinate when moisture is received.

Coster (6*p*) reported the results of comparative field scale tests of seed from Russia and that collected at Missoula, Mont., in 1942. Seed of each origin was given the same pretreatment. In every case the Missoula seed established most satisfactory stands whereas the Russian seed was practically a failure. Regardless of whether Russian or Missoula seed was vernalized or soaked there was no discernible difference between the stands.

Coster also reports that where irrigation is used no special pretreatment of seed seems to be necessary. Tests indicated that where untreated seed is sown in dry soil and the soil then saturated and kept wet, good emergence is secured. In other words, the soak treatment is given in place and the seed respond favorably to it.

Kluender (21*p*) also reported that under wet conditions such as existed in the spring of 1943 on the muck soil at Saginaw, Mich., untreated seed germinated as quickly and as fully as treated seed. Furthermore, in late June under excellent moisture conditions in the Red River Valley of Minnesota, untreated seed germinated and emerged earlier and better than treated seed. Obviously, however,

one cannot depend on having optimum moisture conditions except where irrigation facilities are available.

Coster found that seed collected in Montana in May 1943 had not become dormant by November. Freshly collected mature seed sprouted quickly when planted immediately after collection. These findings seem to agree with those of Poptsov (51).

Seed sown the same season it is collected gives the best germination. Seed collected the previous season may require presowing treatment as there is a definite period of dormancy which begins sometime after harvest.

Storage must be under such conditions as will insure maintenance of adequate seed moisture. Proper seed moisture is also an essential factor in relation to sowing by mechanical means.

The moisture and temperature requirements of germination are apparently delicately balanced. The process requires adequate but not excessive moisture and takes place only within a limited temperature range.

Land Selection

In the selection of fields for the cultivation of kok-saghyz, attention must be given to the history of the field, particularly in regard to previous crops, cultivation practices, weed seed content of the soil, and to the vegetation and management of surrounding fields. The results of tests emphasized the need for exercising great care in the selection of planting sites.

In 1943 in deciding upon particular fields within areas having the necessary qualifications as to soils, temperature, moisture, etc., advantage was taken of the experience and knowledge of local conditions possessed by State college and experiment station personnel dealing with crops whose cultural requirements were thought to be similar to those of kok-saghyz.

The soil on the Pease tract at Seneca Falls, N. Y., proved too light, hence subject to blowing, too low in organic matter, and too subject to drought. Moreover, the tract was too steep and rolling for easy machine cultivation and there was considerable washing during heavy rains. The Ontario silt loam on a nearby tract did not prove adaptable because of severe crusting which prevented emergence and it was too stony for careful cultivation while the plants were small.

In Michigan, one selection of sandy loam and Brookston loam was made overlooking the fact that there is a poorly drained phase of these soil types. The area leased proved to be in that phase. Heavy rains throughout the season kept the soil saturated to the extent that the plants failed to develop satisfactorily and the wet soil could not be cultivated properly.

While attempts were made to utilize fields which had been previously planted to clean-cultivated crops the weeding problem was increased greatly by germination and growth of weed seeds from previous years stored in the soil. This condition was much worse on the peat soils than on the mineral soils. The weed problem on a test plot at East Lansing, Mich., was further increased by seed from adjacent areas of weed growth. In general, results were much better where kok-saghyz followed such crops as sugar beets or potatoes, and were unsatisfactory on land which had previously been planted to grain or corn or which had been in pasture.

Ground Preparation

Lysenko (27, 28) emphasizes proper ground preparation as one of the most important factors for successful establishment and growth of kok-saghyz.

Kok-saghyz, like most root crops, requires deep plowing. The effect of depth of plowing on the yield of roots is shown by the following figures (21*p*):

Depth of plowing (inches):	Roots per acre (pounds)
5.9-----	589
7.9-----	1,481
9.8-----	1,776

Lysenko says that plowing should be done in the fall of the year. Altukhov (2) notes that irrigated soils require deep plowing followed by harrowing immediately before sowing. Spring plowing is discouraged, as such treatment tends to dry out and otherwise disturb the uppermost soil layer. Lysenko specifically warns against re-plowing or deep working of the land in the spring but he does not outline procedures for spring preparation.

In the early spring as soon as equipment can be used the fall-plowed land should be disked or floated two or three times. If the large soil lumps cannot be broken into a fine mulch the field should be harrowed several times with a heavy harrow. It is advisable that this harrowing be very shallow, since a surface mulch of loose consistency will dry out and yet protect the moisture relationships of the soil layer immediately beneath. The well worked, level, porous top layer should be about $\frac{1}{2}$ -inch thick. Harrowing should be done in several directions on soils which have a tendency to crust on drying (66). All presowing ground preparation should be completed in as short a time as possible and be followed immediately by seeding (36).

Milner (36), Zasiadnikov (66) and other Russians likewise recommend fall plowing in the preparation of a fine seedbed. The primary purposes of preparation at this time are to secure the mellowing effect of frost action, to secure a compact upper layer of soil retentive of

moisture and promoting capillarity, and to obtain a thin dust mulch to prevent loss of the soil moisture needed to insure seed germination. The small seed must be sown about $\frac{1}{4}$ -inch deep and hence soil moisture must be retained as close as possible to the surface.

Spring preparation of the ground was necessary in the 1943 operation of the Emergency Rubber Project, except on land held over in Montana. However, it was possible to lease some land which had been fall-plowed. The Plainfield, Wis., peat had been fall-plowed about 12 inches deep. Two of the fields at Moorhead in the Red River Valley of Minnesota and one near Crookston, Minn., had been fall-plowed to a depth of about 5 inches instead of the desirable deep plowing. In addition, three fields at Crookston had been summer-fallowed in 1942. Most of the fields at Missoula, Mont., had likewise been kept fallow after the failure of the 1942 kok-saghyz plantings. All other areas selected for sowing in the spring of 1943 required complete spring ground preparation.

It was recognized from Russian publications and from the similarity of kok-saghyz seed to the seed of other crops known to require careful ground preparation that a well-prepared seedbed would be necessary to permit uniform sowing at proper depth and to secure favorable germination, satisfactory emergence, and rapid early growth of the seedlings.

Concerning ground preparation advice was sought from county agricultural agents, State college agronomists, and the more progressive farmers in each locality. Their recommendations paralleled standard practices of the locality for ground preparation for sugar beets, table beets, onions, and carrots.

In Montana in the spring of 1943, snow remained on the ground much later than usual and unseasonable rains in other areas made it necessary to alter the plan of ground preparation. It was generally necessary to disk and harrow the fields deeply to dry out the soils rather than to take action to conserve moisture. Fields with mineral soil were plowed deeply, disked twice at right angles, harrowed lightly two or three times and the soil then compacted with either a plank float or a cultipacker. Frequent rains often made it necessary to reprepare the surface mulch. Knutson (24p) reports that in the final preparation before sowing, the combined use of a cultipacker followed by a spike-tooth harrow, with the teeth set almost flat, resulted in a greatly improved seedbed. After rain the seedbed was harrowed lightly to reestablish the mulch. Where the wet period was prolonged it frequently became necessary to disk the unsown area lightly before harrowing in order to destroy weeds which had established themselves. If deep disking proved necessary to destroy the weeds the use of the cultipacker to compact the soil again was desirable.

In the Red River Valley concern was expressed over the probabilities of wind erosion on the fields. It was recommended that a rough surface with small ridges of soil be left by light harrowing at right angles to the prevailing wind direction. Actually no appreciable blowing was experienced in 1943. The wind erosion on the sandy soil of the Pease field in New York might have been reduced by ground-preparation treatment similar to that suggested in the Red River Valley.

In Minnesota the customary plowing depth is 5 inches, less commonly 6 inches. At root harvest it was found that kok-saghyz roots penetrated below this plowsole line. At Stewart, Minn., when the root digger pushed forward at a depth of 8 to 9 inches, a shearing effect took place at the plow line, breaking the roots at that point. Thus the pieces of roots in the 5- to 9-inch depth were lost in the harvesting process. Plowing at least 9 inches deep would probably obviate this difficulty and at the same time would encourage growth and development of the plant, but there are few soils on which such deep plowing could be done without turning up large amounts of subsoil.

The importance of proper ground preparation cannot be over-emphasized. A rough and uneven seedbed will cause trouble in sowing, later in emergence, and still later in cultivation.

When the seedbed is finished it should be level, smooth, very firm, and free of clods. It should be prepared as well as an onion field or fields of other fine-seeded crops. Whatever the degree of preparation may be, extra efforts in initial ground preparation will mean a later saving in weeding, cultivation, and loss of seedlings due to various causes.

The most satisfactory seedbed on mineral soils is obtained after plowing by first using a disk, spring-tooth harrow, or field cultivator (fig. 7). This operation should not be done too deeply or it will result in too loose a seedbed. It should preferably be done crosswise to the direction in which sowing is intended, especially when a disk is used, so as to avoid ridges and depressions parallel to the plant rows. Such ridges or depressions may not cause difficulty during sowing, depending upon the type of seeder used. But they will most certainly cause trouble during cultivation where the result will be much covering of plants and deep cutting on the ridges while the surface of the depressions may not be touched by the cultivator.

If the field is uneven or wavy, because of former cultural practices, a heavy float or leveling board should be used immediately following the first ground preparation. Leveling should be done diagonally across the field and repeated if necessary, at right angles to the first direction. Floating serves three purposes: it levels the surface, breaks up many clods, and helps create a firm seedbed.



FIGURE 7.—Cultipacker and spike-tooth harrow being used to level and firm kok-saghyz seedbed. (Forest Service—F-426628.)

After floating, the area should be harrowed at least twice, crosswise, diagonally, or both. A spike-tooth harrow with adjustable teeth is preferable. During the first operation the teeth should be set fairly straight; during the second and following operations the teeth should be laid back so as to give a pulverizing and packing effect.

The ground should then be cultipacked and worked again with a spike-tooth harrow. A very light harrow, or one with adjustable teeth, can be used for this purpose and may be attached behind the cultipacker. If an adjustable-tooth harrow is used the teeth should be laid back. The cultipacking will result in a firm seedbed kept moist by capillarity during the germination period. The smooth surface and light mulch created by the last light harrowing will, under ordinary weather conditions, prevent excessive evaporation.

None of the deeper types of preparation, such as disking, should be done when the soil is wet. Working the soil under such conditions will generally result in "clodding." It is better to stir the topsoil with a light harrow to facilitate drying before undertaking any other cultivation.

Most of the soil-preparation operations should be done during the late summer and fall preceding sowing so that frost action may make

the soil light and friable. Only the application of fertilizer and a light working of the topsoil should be done in the spring to eliminate the danger of working the soil up into clods and to preserve soil moisture.

Ground preparation on peat soils varied a great deal from that on mineral soils. In 1943, peat areas in Minnesota were flooded until the first part of July and soil preparation had to be started while the ground was still saturated. It was soon found that only crawler-type tractors could be used and that even these had to be equipped with wooden extension cleats. Disks and field cultivators were used for the initial ground preparation. The disk seemed to do a better job of exterminating the weeds. After disking, the fields were harrowed with a spike-tooth harrow. After several harrowings the seedbed still remained very rough and loose. The general practice is to pack the soil by means of a heavy roller following harrowing. This was tried, but because the wet soil stuck to the roller use of this equipment had to be given up, and floating, using a heavy plank, was resorted to instead. A fairly smooth seedbed resulted.

Ground preparation for cultivated peat soils followed the general practices on mineral soils. Based on the experiences of 1943 and 1944, it may be stated that these soils are apt to be too wet in early spring to permit preparation for early sowing unless they are drained by surface ditches and either tile or "mole" drains. In the Everglades section of Florida "moles" serve for both drainage and subirrigation.

As peat soils hold the frost longer in the spring, it is extremely important that they be plowed in the fall. Deep disking in the spring aids in drying out the surface soil. Anderson (*1p*) used a 12-foot Case cultivator satisfactorily to dry the surface soil. For these operations ordinary farm-tractor equipment is not suitable, but crawler-type tractors with cleat extensions on the tread proved satisfactory.

Two types of peat soils near Aitkin, Minn., were used in 1943—peat which had previously been cultivated and thus was well decomposed, and raw peat.

An attempt was made to provide a proper seedbed on the State field of uncultivated peat at Aitkin, Minn. In a test a 22-inch breaking plow and a heavy crawler-type tractor turned the heavy sod under to a depth of 10 to 12 inches. However, it had been noticed that in a portion of the Gleason field little decomposition and disintegration of sod took place after a full year, and it was anticipated that considerable difficulty would be experienced in harvesting roots from such sod areas. In order to break up the sod it was necessary to work the area three times with a heavy 4-foot tandem disk plow followed by three diskings with a 7-foot tandem disk, after which the 22-inch breaker plow was used. The usual disking, harrowing, floating, and rolling resulted in a reasonably good seedbed, but at an ex-

cessive cost. An additional area was prepared during the summer and fall for fall seeding. An Athens heavy-duty, brush disk was used seven times and the tandem disk eight times.

While experience during the year pointed out ways and means for subduing wild or raw peat lands, the suitability of such lands for kok-saghyz could not be given satisfactory trial. It is believed that such lands should be used for other crops for a few years before being seeded to kok-saghyz.

It is essential that capillarity of peat soils be restored by heavy rolling after plowing and surface preparation. At Aitkin a 4-foot roller weighing 3,000 pounds pulled by a 15 hp. crawler-type tractor was used and in order to speed up the work another roller made from three gasoline drums filled with concrete was used with a 10 hp. crawler-type tractor (1*p*). A heavy 10-foot roller filled with water was used at Plainfield, Wis. (15*p*). In the absence of a heavy roller at Saginaw, Mich., Milnes (28*p*) used a cultipacker and secured reasonably satisfactory results. Mays (9*p*) found it necessary to use a cultipacker with a heavy plank float at Klamath Falls, Oreg., to secure a satisfactory seedbed, although here the availability of water for subirrigation on this tract more or less eliminated the necessity for compacting the soils to insure capillarity.

Land to be used for fall or winter planting requires preparation during spring or summer. Light harrowing at intervals, or use of shallow cultivation or weeding devices is necessary to control weeds without causing excessive loosening of the soil after preliminary ground preparation.

Knutson (24*p*) emphasizes the need for proper timing of ground preparation operations and for having sufficient suitable equipment available to do the required work at the proper time. Farmers in the Red River Valley of Minnesota are equipped to work their land 24 hours a day when conditions permit. Project tractors were not equipped with lights and in several instances, before sowing was completed, rain made it necessary to delay operations several days. Moreover, there was not enough equipment to work several fields at the same time.

While the methods employed in ground preparation will differ with the soil type and the equipment available, the best general practice appears to be deep loosening of the soil with maintenance of a compact though friable upper layer to retain moisture and otherwise insure good germination and emergence.

Except for deep plowing, problems presented by kok-saghyz in ground preparation do not differ materially from those encountered with any other fine-seeded root crop.

Soil Fertility and Fertilization

Russian articles regarding soil fertility include such statements as: "The most important factor in the culture of kok-saghyz is fertility of the land used." "Its cultivation on highly fertile land is one of the most important conditions for success." "Kok-saghyz requires barnyard manure and mineral fertilizer, irrespective of the fertility of the soil and the nature of its predecessor." Such statements along with many others stress the importance of fertility in the production of kok-saghyz plants.

Mikhailov (34), on analyzing soil specimens from kok-saghyz fields in various parts of Russia, noted that, in general, high root yields were obtained on soils with a neutral or slightly alkaline reaction and that the plant will not thrive on soil with a pH below 4.5. On acid podsol loam soils tests have shown that liming promotes more vigorous growth and increases root weight, yield of roots per acre, percent and total yield of rubber, and density of plants. The most favorable effect on acid podsol soils was obtained with a treatment of 2.8 tons of lime per acre.

Fertilizers commonly used in the U. S. S. R. are complete mineral fertilizers, manure, cottonseed cake, and peat (2). They are applied to the soil at different periods in the culture of the plant and introduced in different ways (3). The main fertilizer may be plowed or disked into the soil in the fall to become available when the roots reach deep into the soil. To support early growth, mineral fertilizers may be applied previous to or at the time of sowing. Supplemental fertilizing may be done once or twice during the growing season; first when 2 or 3 leaves have formed and again when flower buds appear. This supplemental feeding, in dry or liquid form, should be introduced as close to the rows as possible without endangering the plants by burning and at a depth of 1.5 to 2.0 inches for the first treatment and 4.0 to 4.7 inches for the second.

In areas under irrigation fertilizers applied before sowing are placed at the bottom of the furrow to eliminate the danger of producing high concentrations of salts in the upper soil layers while the plants are young (2).

The effect of time and depth of application of the main fertilizers on the yield of roots and rubber is shown in the following figures (3):

	Fresh roots per acre (pounds)	Rubber in dry roots (percent)	Rubber per acre • (pounds)
No fertilizers.....	3, 356	5. 9	44. 0
Fertilizers (nitrogen, 53 pounds per acre; phosphorus, 66 pounds; potassium, 40 pounds):			
Introduced in the spring before harrowing.....	4, 909	8. 7	105. 7
Introduced in the fall before plowing.....	5, 489	10. 1	137. 2

The complete role played by individual fertilizer elements is not understood, but experiments conducted by Neuman (41) indicate that light applications of nitrogen tend to increase rubber content of roots whereas heavy applications reduce the content. In dry seasons increased application of nitrogen prolong the growth period and thus permit greater accumulation of rubber. It is recommended that to obtain this increase in yield both nitrogen and phosphorus be applied in a 1:1 ratio. Nitrogenous fertilizers do not increase and may even decrease carbohydrate accumulation in the roots, whereas phosphates and potassium stimulate this accumulation. Phosphates have a variable effect on rubber accumulation. During moist seasons they increase rubber and in dry seasons decrease it. Phosphate tests conducted by Mikhailov (35) show that increased amounts of phosphates during the early life of kok-saghyz cause the plant to make rapid growth especially where application is made close to the roots.

Tests conducted by Drobkov (13) indicate the importance of boron and manganese, two elements which greatly influence the yield of roots and content of rubber.

The data on Russian experience with fertilizers were not available during the spring sowing season of 1943. However, the 1942 adaptation and production tests indicated increased yield on the better agricultural soils in comparison with the low fertility, sandy soils of Forest Service nurseries, even though the latter had received several applications of fertilizer during the growing season as well as annual applications of compost fortified with complete fertilizers.

Fertility tests on these light sandy soils indicated quite conclusively that kok-saghyz requires a fertile soil with high organic content for the best seed and root yields (4p). The nursery soils were on the acid side (as required for coniferous tree production). Stoeckeler (40p) indicated that use of 480 pounds per acre of a high analysis N-P-K fertilizer supplemented by a ton of lime per acre resulted in a calculated sevenfold increase in seed yields and in double the root yield.

Greater vigor was noticed in plants on small areas where the organic content of the soil was higher. In the 1943 production program all fields were to be fertilized in accordance with standard practice for root crops in the locality and following the advice of State college soils experts and agronomists, or of the local county agricultural agents. At the same time comparative tests were to be undertaken to determine the value of commercial fertilizers and manures.

Coster (6p) reports a 100-percent increase in seed yield over areas without treatment when manure and fertilizer were supplied at the rate of 20 tons of manure plus 100 pounds of treble superphosphate per acre. He also reported no significant differences in seed, root yield, or rubber content where various amounts of commercial fer-

tilizer were applied, nor could differences in rubber content be traced to the several fertilizer practices tested.

At Plainfield, Wis., a side dressing of 3-9-18 commercial fertilizer applied to peat soil at the rate of 250 pounds per acre, following an initial application of 1,070 pounds of 0-14-14, resulted in a slight but consistent increase in the computed fresh weight of roots per acre.

Kluender (21*p*) reports more plants per linear foot on unfertilized peat soils at the end of the growing season than where 600 or 1,000 pounds of 3-9-18 fertilizers were used, but the weight of the individual roots averaged nearly 50 percent heavier where fertilized. Since there were many undetermined factors, it is not suggested that the lighter stands were a direct result of the fertilizer treatment nor that the heavier weight of the individual roots should be attributed solely to the fertilizer.

Bureau of Plant Industry, Soils and Agricultural Engineering investigators (38*p*) conducted a number of detailed fertilizer tests at St. Paul, Minn., and other locations, as well as greenhouse studies of the different fertilizer treatments.

Tests were started in the spring of 1943 on kok-saghyz plantings sown in 1942 and 1943 to determine the kinds and amounts of fertilizer required to obtain the highest yields of roots, rubber, and seed per acre on mineral and peat soils at different locations. Many of these tests failed because of excessive cold and wet spring weather or were abandoned before the season was over because of unfavorable soil or other conditions. Several of the tests carried through the season showed no response to the fertilizer treatments. There were indications that the heavy applications of fertilizer used on some of the dry western soils caused a decrease in the stands of kok-saghyz. The level of fertility of some of these soils was adequate for kok-saghyz production and additional fertilizer had no effect on the yields of roots and rubber or the rubber content of the roots.

There is a suggestion in the results that perhaps best root, rubber, and seed yields can be expected when phosphorus is applied in the spring and nitrogen and potassium are supplied before the full-flowering period in the summer ($\frac{1}{2}$ of the nitrogen and potassium supplied at planting time, $\frac{1}{4}$ at the bud stage, and the remaining $\frac{1}{4}$ at full-flower).

From greenhouse tests at St. Paul, Minn., on raw, acid peat from fields at Aitkin, it was concluded that applications of nitrogen, phosphorus, and potassium will not produce satisfactory yields unless heavy applications of lime are made in advance. If fine limestone is used, it can be applied immediately before sowing, but much better results would be obtained if applications were made 6 months earlier. If coarse limestone is used, it should be applied as much as a year in advance.

Greenhouse tests on peat soil from Klamath Falls, Oreg., fields showed increased yields where a mixture of such minor elements as boron, zinc, manganese, and copper were used.

Building up an adequate knowledge of the fertilizer demands of kok-saghyz requires continued study of the mineral nutrition of the plant and detailed analyses of such soils as may be selected for its production. It is probable that proper use of fertilizers could do much to overcome the weak early growth which has characterized kok-saghyz.

Fertilizer requirements will depend upon the fertility level of soils selected, upon the purpose for which the plants are being grown, and upon the balance which must be obtained between rate of growth and rubber production.

Analysis of a few samples of rubber in 1944 showed rather high content of copper, iron, manganese, and other elements generally considered to be objectionable in rubber because of their effects on its quality and aging properties. When selecting soils as well as when applying fertilizers attention should be given to the presence of these elements in forms which can be absorbed by the plant.

Time of Sowing and Its Effect on Germination and Emergence

The first plantings of kok-saghyz were made as soon as possible after the arrival by plane of a small quantity of Russian seed in May 1942. No information was then available as to the proper time of sowing. On the basis of its apparent similarity to other crops it was assumed that kok-saghyz should be spring sown.

When translations of Russian articles became available it was revealed that Russian investigators had made several studies of the relation of temperature to germination of kok-saghyz seed. They reported that in the spring seed begins to germinate when the soil temperature reaches 41° to 50° F., but that a high degree of germination does not occur until the soil temperature reaches 77°. Late fall sowing is supposed to result in somewhat more uniform germination because seed sown at that time does not germinate until early spring (25). The lower temperatures characteristic of early spring make for slower but uniform germination. Zasiadnikov (66) reports that difficulty has been experienced in obtaining good, uniform stands of seedlings from spring sowing. However, spring sowing has several advantages over fall sowing and is recommended by Altukhov (2) for every region in the U. S. S. R. in which kok-saghyz is commercially cultivated.

It is reported (1) that as late as 1940, two-thirds of the entire kok-saghyz area in Russia was planted before winter. Fall sowing has

the advantage of not conflicting with other farm duties and considerable care can therefore be given to this operation. But it carries a high risk in assurance of a successful stand. One report (1) states that it is essential that seed planted in the fall not begin to sprout before winter. The weather probabilities must be weighed carefully to select the proper sowing date. Fall sowing has sometimes resulted in failure due to freezing of seedlings which have germinated too early in the spring, as well as to formation of early spring soil crusts (2). Altukhov states that for several years and for all regions of commercial cultivation in the U. S. S. R. fall sowings of kok-saghyz always produce considerably lower yields than spring sowings.

It was anticipated at the beginning of the 1943 program that all sowing would be done in late April or early May. Actually, only a small acreage was sown during that period because of unseasonable weather conditions including a late spring, heavy rains, and flooding. A considerable portion of the early seeding was lost because the soil became too wet for cultivation and weeding. After the early sowing, weather conditions were exceptionally fine for vigorous weed growth and in some cases it appeared more economical to resow after the weed crop was destroyed. Sowing was done at Moorhead, Minn., on April 21 and 22, followed by other sowing in the periods April 28 to May 1 and May 3 to 4. At Crookston all sowing, except for one field, was done during the last half of May. At Plainfield, Wis., sowing was started on May 13 and finished on May 18. In Montana and Oregon sowing was done during May.

Except for the Plainfield area, the peat soil was too wet for any sowing until June and at Seneca Falls, N. Y., the sowing period extended until July 1.

A spring season total of 750 acres was projected and 655 acres or 86 percent was actually sown. Of the original acreage sown 28 percent was lost because of weather conditions or some other reason. Part of this loss was made up by reseeding once and sometimes twice. But on a considerable part of the 108 acres reseeded stands were light and unsatisfactory.

The total acreage brought through to root harvest amounted to 522 acres or 80 percent of the original area sown. This percentage compares favorably with the accomplishment by farmers in the several kok-saghyz planting areas, many of whom failed to plant their proposed acreages of other crops or were forced to change to some crop which normally is planted in late spring or early summer.

Table 5 shows the acreages sown, reseeded, and carried through the 1943 season. "Carried through" does not necessarily mean that the crop was a successful one in terms of stand, growth, and yield of seed,

roots, and rubber; it simply means that a sufficient stand was secured to warrant weeding, cultivating, roguing, and other operations included in the experiment.

TABLE 5.—*Acreages sown to kok-saghyz in 1943*

SPRING

Location	Original sowing				Reseeding			
	Sown		Carried through		Sown		Carried through	
	Mineral	Peat	Mineral	Peat	Mineral	Peat	Mineral	Peat
	<i>Acres</i>	<i>Acres</i>	<i>Acres</i>	<i>Acres</i>	<i>Acres</i>	<i>Acres</i>	<i>Acres</i>	<i>Acres</i>
Moorhead, Minn.....	144	-----	127	-----	5	-----	5	-----
Crookston, Minn.....	146	-----	98	-----	175	-----	41	-----
Stewart, Minn.....	12	-----	0	-----	8	-----	0	-----
Aitkin, Minn.....	-----	47	-----	34	-----	3	-----	1
Plainfield, Wis.....	-----	39	-----	39	-----	-----	-----	-----
Saginaw, Mich.....	24	74	19	60	-----	-----	-----	-----
Missoula and Frenchtown, Mont.....	56	-----	36	-----	10	-----	7	-----
Lewistown, Mont.....	1	-----	0	-----	-----	-----	-----	-----
Miles City, Mont.....	3	-----	2	-----	-----	-----	-----	-----
Bonners Ferry, Idaho.....	1	-----	1	-----	-----	-----	-----	-----
Klamath Falls, Oreg.....	26	26	9	23	-----	-----	-----	-----
Seneeca Falls, N. Y.....	25	21	8	0	7	-----	2	-----
Burlington, Vt.....	10	-----	10	-----	-----	-----	-----	-----
Total.....	448	207	310	156	105	3	55	1

FALL

Belle Glade, Fla.....	-----	17	-----	9	-----	8	-----	7
Napoleonville, La.....	4	-----	0	-----	-----	-----	-----	-----
Guayule project.....	13	-----	13	-----	-----	-----	-----	-----
Total.....	17	17	13	9	-----	8	-----	7

¹ Includes second reseeding of approximately 15 acres.

There is no doubt that early sowing under good conditions will result in the best stands in regard to root yield and probably even more in regard to the first year's seed yield. The latter was particularly evident in the Wagner field at Crookston, Minn., originally sown on April 24, 1943. The seed yield from the original sowing was 18.9 pounds per acre as compared with 4.5 pounds per acre on that part of the field which was reseeded on June 11.

The size of plants resulting from later sowings will, of course, be somewhat smaller than those from earlier sowings. For instance, at the time of lifting, the root yield on the original seeding on the Wagner field at Crookston was 3,381 pounds per acre, while the yield on a reseeded part of the same field was 2,793 pounds per acre. Both areas were harvested on the same day and the number of roots per linear foot was about the same. The average root weight from the first sowing was 10.8 grams while on the reseeded area the roots averaged 9.1 grams. (28.349 grams=1 ounce av.)

On the Bekkerus field at Moorhead, Minn., originally sown on April 22, the root yield at the time of harvest was 2,208 pounds per acre. The portion of this field which was reseeded 5 weeks later, on May 31, yielded 2,372 pounds per acre. That the reseeded part of the field gave a higher yield was due to the greater density of plants resulting from the reseeding. The average root weight in the original sowing was 5.5 grams compared with 4.4 grams in the reseeded portion.

Both these fields were reseeded under favorable weather conditions and sufficiently early for the plants to take advantage of the best part of the growing season.

It is certainly preferable to sow somewhat later under good seedbed and moisture conditions than earlier under poor conditions. Very late seeding, however, is a gamble. Because of unfavorable weather conditions during the spring and early summer of 1943, some late seeding had to be done. A good deal of this was unsuccessful, mostly because the weather turned hot and dry for several days following sowing, thus preventing germination or killing newly germinated seedlings. Generally, sowing should be completed, at least on mineral soils, by June 1 in the Red River Valley of Minnesota. On peat soils in the North, under ordinary conditions, no sowing should be undertaken after June 15.

Two Red River Valley fields which were partly reseeded rather late and during hot weather, show the comparison between the original sowing and late reseeding under poor conditions:

	<i>Plants per foot (number)</i>	<i>Average root weight (grams)</i>	<i>Yield per acre (pounds)</i>
Woodstrom field:			
Original seeding, May 1, 1943.....	4. 3	8. 8	2, 595
Reseeding, June 29, 1943.....	1. 4	7. 9	774
A. Thureen field:			
Original seeding, May 20, 1943.....	7. 0	6. 9	3, 266
Reseeding, June 30, 1943.....	3. 1	6. 1	1, 274

Sowing Methods

According to the Russians, sowing should be done with a disk drill to which are attached rollers to firm the seed in the soil (2). Prior to seeding, a filler is prepared which is then mixed with the seed to obtain a uniform rate of sowing and prevent moist seed from blocking the drill. Zasiadnikov (66) reports that millet chaff and dry sawdust are considered good for this purpose. Millet chaff should first be freed of weed seed or roasted to kill the weed seeds. The seed and filler are thoroughly mixed in a predetermined proportion. During the sowing the mixture should be frequently stirred to insure uniform distribution. Altukhov (2) states that where sawdust is used as a

filler, a ratio of 1 part seed to 15 parts fine sawdust by weight is satisfactory.

It has also been suggested that kok-saghyz be sown in specially prepared soil balls (66). Such seed balls might have the advantage of obtaining better distribution. Seedlings from such balls, germinating in clusters, are better able to break through soil crusts. Peas and vetch which are sown with the balls germinate early and mark the rows for early cultivation. Each seed ball produces 3 to 5 plants. When sown uniformly at the recommended rate and row spacing, they may produce a stand of from 65,000 to 90,000 plants per acre. Seed balls are prepared by molding stratified seed, fertilizers, and soil. They are then dusted with chalk so they will flow freely through a grain or vegetable drill.

Many sowing practices used in the cultivation of sugar beets in the U. S. S. R. were applied to kok-saghyz culture (60). The single-row sowing is the commonest used in the U. S. S. R. and can be drilled four rows at a time with horse-drawn drills or eight or nine rows with tractor-drawn drills (66). Altukhov (2) reports that on weed-free areas rows may be sown in pairs or three or more rows together leaving strips for cultivation between the beds thus created. By sowing rows in this manner the number of plants per acre is increased, but such spacing often makes subsequent care to the crop more difficult, especially if the field is weedy and cultivation within the rows is required.

Lysenko (28) says that under normal conditions, the more shallow the sowing, the quicker and better the germination. Seed sown deeper than 0.8 inch usually fails to germinate, as does seed sown too shallow in dry soil. The best results in the U. S. S. R. have been obtained when seed was sown 0.2 inch deep. This shallow sowing requires measures to retain the moisture in the upper soil layer.

It is reported that on many farms in the Kharkov region drill rows after sowing are covered with fine humus (50). The humus prevents crust formation and retains soil moisture in the upper soil layer. It is applied at the time of sowing in strips about 2.5 inches wide and 0.2-0.4 inch deep. Another practice is to sprinkle the rows with sifted rotted manure (2). When humus or manure is used, sowing should not be deeper than 0.2 inch. The following comparison shows the effect of humus and rotted manure on kok-saghyz root yield (3):

<i>Root yield per acre without covering (pounds):</i>	<i>With covering (pounds)</i>
2,249-----	3, 132
1,625-----	2, 008
1,713-----	2, 704
2,856-----	4, 302

In Russia kok-saghyz seed is sown at the rate of 1.8 to 2.6 pounds per acre in single or paired rows, 2.6 to 3.6 pounds per acre in triple rows, and 3.6 to 4.9 pounds per acre where 4 or 5 rows are sown together (2). In the first plantings in this country seed was sown at approximately 3 pounds per acre (in single rows) in conformity with the Russian practice. Later when the low viability of the seed was recognized, the rate of sowing was increased to as much as 5 pounds per acre.

Although Russian papers suggest sowing with sugar-beet drills, the 1942 production tests at Missoula, Mont., indicated that sugar-beet drills and similar equipment available on farms in that locality were poorly adapted to the fine seed of kok-saghyz. Jones (19p) reports that in 1942 at Cass Lake, Minn., three types of seed drills were tried, the forest tree-seed drill adjusted to four rows at one time, a single-row common garden seed drill, and a 4-row unit of Planet Junior make, attached to the rear cultivator bar of a Farmall "A" tractor. The garden seed drills did the most satisfactory work. Coster (5p) found that it took six men with individual hand-propelled garden drills to do as much sowing as could be done with a multiple-unit tractor-drawn drill in 1 day.

In planning the production program, the field sowing, cultivating, and seed picking were integrated to facilitate mechanization of the field operations.

A rigid 8-row type of drill pulled by a tractor was secured for trial. It worked satisfactorily in the Red River Valley of Minnesota only where the surface of the ground was absolutely flat between the wide-spread wheels of the drill unit. Where the ground was uneven one or more drills dropped the seed on the surface of depressions or sowed too deeply in slight rises.

On the other hand, the individual seeding units attached to the rear cultivator bar followed the contours of the ground and did a satisfactory, even sowing job (fig. 8). The depth of sowing was controlled readily but it was necessary to substitute a light chain drag in place of the regular covering device. Some difficulty was met in attempting to sow when the soil was too wet and when the pretreated seed was too moist. Moist seed has a tendency to adhere in lumps and not flow readily from the drill.

When sowing was first begun it was assumed that the pretreated seed could not be dried below 35 percent moisture content without injury to the seed or inducing a return to dormancy. Thirty-five percent moisture resulted in an uneven flow of seed. The period of sowing was extended for nearly 3 months because of weather conditions and during this time it was discovered that the seed could safely be dried below 35 percent. Drying to 25 to 30 percent allowed an



FIGURE 8.—A multiple-row, tractor-attached seeder made up of model 300-A Planet Junior units. (Forest Service—F-426632.)

even flow of seed, but it was still necessary to have a man follow the drills and to keep constant watch of the drills and the seed flow. The Planet Junior drill is so constructed that one can see the seed fall to the ground.

The 8-row Planet Junior seeder, built up from seed boxes No. 300A, proved to be the most satisfactory machine for it could be set and maintained at a desired depth more easily than the pull-type seeder. Also, because of the short distance from the seed boxes to the ground, there is less chance of the seed clogging in the seeder tubes and a more even flow of seed is obtained. Since this machine is mounted on a cultivator bar, attached to the tractor, it has, at least on mineral soil, a further advantage over the pull-type seeder in that it can be turned more quickly and in a shorter space at the end of the field.

The lifting of the seed drills of the Planet Junior 300A type seeder, when turning, is done from the tractor by hydraulic lifts whereas the drills of the pull-type are, of necessity, hand operated. Also, where the ground is somewhat uneven the more flexible seed drills of the 300A type will follow the contours while the pull-type seeder will push through the obstructions and seed too deeply on the high spots.

On the ridges which occurred in some of the fields the shoe of the pull-type seeder left tracks up to 2 inches deep. The seed was sown

at the depth of $\frac{1}{2}$ to $\frac{3}{4}$ inch below the seeder shoe. Winds and heavy rains later filled these tracks with soil. Numerous misses and failure spots resulted.

The agitator attachments in the Planet Junior 300A seeder are directly over the drill openings and proved much more effective than the agitators in the other type, which are in a horizontal position and cause considerable clogging.

Because of the shortage of rubber tires in 1943, iron-wheel tractors were used. These were hard to handle, especially in steering. As a result, the rows in some of the fields were crooked. To a great extent, use of rubber-tired wheels would have eliminated this trouble. The row marker was set so that steering had to be done over either of the front wheels, that is, the front wheels had to follow the mark. This alignment makes straight steering difficult. The marker should be set for center steering instead. Crooked rows cause considerable difficulty in cultivation.

Time and again depth of sowing proved the most important single factor. It cannot be stressed too strongly that depths exceeding $\frac{1}{2}$ inch will result in poor stands. In using the Planet Junior seeder without tension springs attached, the depth of the seed drills should be set in the third or fourth notch from the bottom, depending on the compactness of the seedbed. If the tension springs are used the seed drills should be set at the second or third notch depending on the firmness of the seedbed.

If the soil is fairly loose or lumpy, the covering device should be taken off and the seed covered by the rear packing wheel only. If the topsoil is especially dry the covering device also should be taken off since it has a tendency to drag in an excessive amount of loose and dry topsoil as well as clods, and thus cover the seed too deeply. Under such conditions it would be safer to delay the seeding a few days until after the first rain has reestablished the capillarity in the topsoil. No germination will take place while the seed lies in the dry topsoil and much seed, if pretreated, will be lost where such conditions prevail for any length of time.

A few more days delay after the soil has been worked has the further advantage of giving the weeds a chance to germinate. These newly germinated weeds are easily killed by a light harrowing. Under especially weedy conditions this practice should always be used. Under such conditions light harrowing at 2- to 4-day intervals immediately prior to sowing will save much labor and expense in weeding later in the season.

The extreme importance of depth of sowing was evidenced in many of the fields in 1943. Because of dry conditions the first half of the first field was sown at a depth of about 1 inch and probably deeper in

places. As rain fell the following night, the seed drills were raised about $\frac{1}{2}$ inch the following day and the rest of the field was sown at this depth. In the second part of the field emergence took place in less than 2 weeks and a fair stand resulted while on the area sown 1 inch deep few plants emerged. The area was carefully checked several times during the following month and it was noted that there was fair germination even though the seedlings did not emerge.

Depth of sowing tests established later showed the same tendencies as indicated in table 6 for two separate fields.

While sand mulching may not be a practical undertaking on large fields because of the amount of dry sand required, a mulch could easily be applied on smaller experimental areas to promote full germination. The increased germination and emergence obtained by using a sand or peat mulch may reduce the sowing rate by one-half. Sowing and mulching can be done mechanically in one operation.

Existing seed drills are sharply pointed and deposit the seed in a narrow V-shaped trench, from the deeper part of which many seedlings fail to emerge. A flat-bottomed seed drill which would deposit the seed in a shallow but broad band about the width of the seeder wheel would probably give better results.

TABLE 6.—*Emergence as related to depth of sowing*

GLEASON TRACT, AITKIN, MINN.—PEAT SOIL

Depth of sowing	Average seedlings per foot			Leafspread 60 days after sowing
	20 days after sowing	30 days after sowing	60 days after sowing	
	<i>Number</i>	<i>Number</i>	<i>Number</i>	<i>Inches</i>
Surface (1st notch) ¹	25.9	20.2	19.6	6.2
Surface—sand mulched ²	41.9	31.2	31.0	6.0
Shallow (3d notch).....	15.8	12.4	11.9	6.1
Medium (4th notch).....	9.3	7.0	7.0	5.1
Deep (6th notch).....	4.0	3.3	3.5	4.6

GROVER FIELD, MOORHEAD, MINN.—MINERAL SOIL

Surface (1st notch) ¹	-----	13.6	7.6	5.2
Surface—sand mulched ²	-----	18.1	13.2	6.1
Surface—peat mulched.....	-----	6.0	9.9	4.2
Shallow (3d notch).....	-----	11.1	9.4	5.0
Deep (5th notch).....	-----	7.1	5.6	4.8

¹ All depths were sown at the same density. Setting the seed drill in the first notch placed the seed on the surface of the soil. The covering devices of the seeder were not used. The only covering was done by the rear packing wheel. Most of the seed was exposed.

² The sand mulch was applied with a single hand-operated Planet Junior seeder at a thickness of about $\frac{1}{8}$ inch immediately following sowing.

Kok-saghyz requires not only a shallow planting but a compact seedbed. The effect of compacting was evident at ends of the fields where equipment was turned around. In filling the seed boxes some seed was usually spilled on this hard ground and later produced dense

clusters of plants. Cultipacked as well as floated strips through various fields, because of the more compact nature of the seedbed and consequently shallower seeding, have shown quicker and better emergence than the looser seedbeds adjacent to these strips.

A part of one field (Bekkerus) at Moorhead, Minn., where the seedbed had been too loose was reseeded a month after the original sowing. The only ground preparation, done prior to the reseeding and disturbing as little as possible the compact seedbed which, during the elapsed month, had been hardened by rains, was the use of a heavy float mostly to scrape off and uproot the weeds that had become established and to level off the tractor tracks. The seedbed was comparatively firm and seeding was shallow, less than $\frac{1}{4}$ inch. Presprouted seed was used. Germination and emergence on this part of the field was rapid and uniform. The rows could be distinguished in 5 days and the reseeding resulted in an excellent stand. The cost of weeding on this area was low because of the destruction of the weed crop prior to seeding.

Germination and Emergence

Russian articles (2, 19, 27, 28) indicate that with proper pretreatment of the seed and with the seed sown in properly prepared moist soil some germination takes place in 5 to 6 days and germination is generally complete in 15 days. Lysenko (27, 28) emphasizes the necessity for testing seed during pretreatment to determine the time at which it is ready to sprout. Altukhov (2) indicates there is usually enough rain in April and May to insure uniform and complete germination so that it is not necessary to rely wholly on capillarity. He recommends that in irrigated areas several soaking irrigations be given. Poptsov (51) found that the range of temperature at which germination takes place is rather limited. Temperatures fluctuating between 68° and 86° F. result in the most prompt and complete germination. He shows that temperatures of 95° F. are damaging. At 44.6° only 8 percent of the seed germinated in 15 days but if enough time was allowed a fairly high percentage of germination was obtained.

Altukhov (2), Koroleva (19), and others called attention to the fact that kok-saghyz produces weak seedlings which grow with difficulty for the first 30 to 40 days. They do not make direct reference to losses in germination and emergence.

Coster (5p) reported that crusting of silt loam soils at Missoula, Mont., and silty clay loam soils at Miles City hindered emergence. He was not able to develop a satisfactory means of breaking the crust without doing considerable damage to the weak seedlings at the same time. This factor was of considerable importance in the production of the very light stands in Montana in 1942. In 1943, Coster (6p)

found that keeping the soil thoroughly wet by irrigation prevented crusting in the same fields where it was so severe in 1942.

Stephenson (39*p*) points out that crusting was not serious at Moorhead, Minn., on the Bearden silt loam in 1943 but that it did prevent some emergence and caused losses in early cultivation. Cultivator teeth broke the soil within the row into clods and where the soil close to or within the row was greatly disturbed the seedlings died. Moore (30*p*) reports that the Bearden silt loam had a tendency to crust whenever even a moderate rain was followed by warm weather but that subsequently the crust slackened and disintegrated. This breaking down of small clods and of the crust is said to be characteristic of these silt loam soils. Frequently rains during the period of emergence softened the soil so as to allow the seedlings to penetrate the crust.

Kirkpatrick (20*p*) reports that the Webster silty clay loam at Stewart, Minn., also crusted. Part of the field was reseeded because of a poor stand and excessive weed growth during the period when the ground was too wet to allow weeding and cultivation. Crusting of the soil was reported to be greater in the reseeded area than it was in the originally seeded area. This may have been due to the greater rainfall and the hotter weather at the time of reseeding.

There was some crusting reported on the Ottawa loamy fine sand at Geneva, N. Y. On the Ontario loam soil at Seneca Falls crusting was severe. Inasmuch as this area was experimentally of considerable importance, strenuous measures were taken to overcome this crusting (31*p*). Each weeder was given a piece of 2- by 4- by 12-inch lumber with nails driven through one end to break the crust at the time of weeding.

Crust breaking to secure satisfactory emergence is a job requiring daily coverage of acreages and fields rather than a small linear footage of row. Such methods as were used on a small scale could not be employed on a production program.

Zehngraff (44*p*, 45*p*) tested the value of a sand mulch and secured a much better stand from the mulched rows but he questions the practicality of this operation on a large acreage basis. Using an application from $\frac{1}{8}$ to $\frac{1}{4}$ inch deep on rows 16 inches apart would require about $1\frac{1}{2}$ cubic yards of sand per acre. Had all of the sowing on mineral soil in Minnesota in 1943 been sanded some 500 cubic yards of sand would have been required.

The Guayule Emergency Rubber Project used a sand cover in their nurseries and developed a spreading device on their seed drills. Sand can be spread economically but the amount required and the necessity of keeping it dry enough to flow evenly would probably preclude its use on a large field scale.

The weak germination and early growth habits of kok-saghyz require conditions favoring easy emergence and rapid development. Important in this respect is freedom from soil and seed borne organisms which cause damping-off under certain conditions. For the first two or three weeks after germination kok-saghyz is very susceptible to damping-off organisms. Damping-off nearly eliminated some 1943 stands on peat at Aitkin.

Sowings were made in the late fall of 1943 on mineral and peat soil in Minnesota and on mineral soils in Montana for comparison with spring sowings. Spring sowing in Minnesota was done on April 13 and 28, 1944, on the mineral soil, and May 23 on the peat soil. Emergence from fall-sown seed was noted on April 19 for the peat soil and on April 22 for the mineral soil. The spring sowings showed emergence in 12 days. A cold wave with the temperature dropping to 22° F. occurred in Minnesota on May 6, 7, and 8 with disastrous results on fall-sown and April 13 spring-sown stands. At that time there were no seedlings above ground from the April 28 sowing, and the final stand was excellent. On May 31 the fall-sown stand was from 0 to 7 plants per linear foot. The stands of the April 13 sowing ranged from 6 to 11 plants while those of the April 28 sowing, which was not injured by the freeze, ranged from 20 to 46 plants.

The thin stand in the fall-sown field can be attributed in part to the fact that this field was blown free of snow during the winter and early spring. The fine dust mulch was also blown away, together with some of the seed. Under these conditions no particular advantage was gained by sowing in the fall or in the early spring. Later spring sowing on peat was delayed until May 23 and emergence noted four days after seeding was equally rapid for dry seed and for "vernalized" seed.

Coster (5*p*) made fall sowings on October 19, October 23, and November 1, 1943. The first emergence was noted on April 1, 1944, and a stand of 38, 40, and 46 plants per linear foot was secured for the three sowings, respectively. Coster (6*p*) also made sowings in the spring on April 15 and May 13, 1944. Irrigation water was not available for the April 15 sowing. There was no emergence for 28 days and the final stand was only 8 plants per linear foot. Of the May 13 sowing only a part was irrigated. As might be expected, germination on the unirrigated stand was delayed and the number of plants averaged 12.8 per foot while on the irrigated portion the plants emerged rapidly with a resulting stand of 29.6 per foot. Coster concludes that in Montana fall seeding is best and cheaper since it requires no irrigation to secure early germination.

More study of germination of kok-saghyz seed under field conditions and of the germinative losses on both fall and spring sowings is essential.

It is known that during the first weeks after sowing losses occurred among the weak seedlings as a result of poor germination, abnormal growth, damping-off, freezing, crusting, and other factors as well as disturbance by cultivation and other cultural operations after emergence.

Cultivation

That Russian kok-saghyz growers had difficulty with weed control, is evidenced by recommendations that a minimum of three to six hand weeding be made during the first year (3, 36).

Although it was known that kok-saghyz has a weak seedling growth and develops slowly for the first month or so while weeds grow rapidly, creating a real problem of weed control, the extent of weed seed contamination in most soils in this country was not appreciated. Altukhov (2) and other Russian writers advise that if weedy soils must be utilized they should be summer-fallowed the year previous to kok-saghyz sowing to secure germination and permit destruction of weeds. The emergency program of experimental production was approved in late winter of 1942-43 and there was little opportunity to select fields on the basis of all the factors now known to be important.

Choice of land in 1943 was primarily on the basis of assumed suitability of soils. Effort was made to select tracts that had been in clean-tilled crops the previous year. As it turned out, the advantage gained by the selection of land which had previously been clean-cropped was largely offset by deep plowing, which turned up many weed seeds, and the nature of the kok-saghyz plant, which made the use of most ordinary methods of weed control difficult and inordinately expensive. All fields were extremely weedy but those which had been clean-tilled for two or more years previous were somewhat less weedy than those which had been clean tilled only the previous year. One year of "black" summer fallow reduced the weeds to some extent.

Weed seeds may lie dormant in the soil for one or more years but, when brought close to the surface by tillage, germinate readily. At Missoula, Mont., most of the area used in 1943 had been sown to kok-saghyz in 1942. Kok-saghyz was a failure on a considerable part of this area in 1942 and the fields had been kept fallow for reseeding in 1943. Even so, the weed problem was serious. Coster (6p) suggested that irrigation water carried many weed seed which were deposited on the fields.

It is clearly evident from the 1943 experience that one of the best ways to reduce the weed population is to delay seeding so that the main crop of weeds may germinate and be eliminated with mechanized equipment. Knutson (24p) and Stephenson (39p) comment on the

fact that in Minnesota the weeding problem was less on the reseeded areas because of the destruction of weeds in reparing the ground. Moore (30*p*) determined that the lowest cost of weeding was on late planted fields where ground preparation before sowing had eliminated most of the weeds.

About the same favorable weather conditions are necessary for germination and growth of weed seed as for kok-saghyz. During continued cold wet weather most weed seed will lie dormant but will germinate and grow rapidly when there is a combination of warm weather and moist soil. A delay of seeding for a week to 10 days during favorable growing weather, followed by shallow cultivation to destroy weeds, will reduce the weeding problem.

Deep cultivation to destroy weeds before sowing is objectionable since it tends to dry the soil, thus making a poor seedbed. Too much delay in sowing, to kill weeds, is undesirable since the length of the growing season will be materially shortened and, consequently, the yield of kok-saghyz will be reduced.

Mechanical cultivation is done between the rows to eliminate plant competition, aerate the soil, and provide a dust mulch to retain moisture. Altukhov (2) and Lysenko (28) suggest that the first cultivation be very shallow but that subsequent cultivations should be progressively deeper. Experience indicates that the first cultivation for weed control must be done soon after seeding. In some cases this so called "blind" cultivation was done by following the row marks left by the seed drills. It was necessary to set the cultivating attachments (knives, duck-feet, deer-tongues, etc.) so as to leave relatively wide spaces on either side of the row. This obviously reduced the weed-killing efficiency of the operation. Cultivation at a distance from the row was also necessary after kok-saghyz had emerged, because of the delicate nature of the seedlings.

To obtain a quick marking of the rows Oliver (31*p*) mixed turnip seed with kok-saghyz seed. However, this seed was heavier than kok-saghyz and tended to settle to the bottom of the seed hopper and to be sown first rather than as a mixture.

Milnes (28*p*) had much better success mixing lettuce seed with kok-saghyz. The rapidly growing lettuce was quite evenly spaced from 2 to 4 feet apart in the rows and was of considerable assistance in early cultivation.

The small size of the young plants and their recumbent habit make it difficult to cultivate close to them. The young plants make very little growth for 2 or 3 weeks or more after emergence and are difficult to see in the row, especially where weeds are numerous (fig. 9). Soil cannot be thrown toward the plants in the row to cover and smother weeds.



FIGURE 9.—Kok-saghyz plants photographed at various ages. Note the slow growth during the first few weeks. (Courtesy L. H. Smith, Vermont Agricultural Experiment Station.)

In Minnesota sowing was done in beds of four rows each but with one-half a bed on either side of the 20-inch space allowed for each tractor tread. In other words, eight rows were sown at one time and this required cultivating equipment be assembled to operate on the same pattern (fig. 10). Damage is done by the cultivator tools clogging, weeds dragging, or soil being thrown onto the weak plants as well as by swinging off the row. Knutson (24p) Moore (30p) Stephenson (39p) and Anderson (1p) comment on the desirability of four-row cultivators inasmuch as four rows can be watched more closely than eight. Use of such equipment would require seeding on the basis of four rows as done at Plainfield, Wis.

It was found that disk cultivator attachments could work not only closer to the rows than other tools but would also cut through trash on the surface or in the soil without greatly disturbing the plants. They were thus able to cover a larger percentage of the area by machinery, leaving a smaller strip to be hand weeded. Ramp (32p) calls attention to the fact that disks throw the soil away from the plants and it is desirable to push this soil back so as to avoid excessive drying out. This operation is done by mounting a "duck-foot" cultivator attachment in the middle of the row space behind the disks.

Ramp points out the need for staggering weeding knives and other attachments to avoid disturbance of soil and plants in the row. With careful driving of the tractor staggered knives can operate within 1 inch or so from the row, thus greatly reducing the space to be hand weeded. Weeding knives should be set at not more than $\frac{1}{2}$ inch below the soil surface for the first cultivation and they should be kept sharp to cut, rather than tear, the soil and weeds. In later cultivation, weeding knives or other tools may be set deeper.

After the plants have developed a spreading rosette of leaves the weeding knives should be reversed so as to cut under the rosette without injury to either the leaves or the roots, or special attachments with shields should be used for raising and protecting the leaves if the weeding knives are employed in the usual manner. Ramp also says that sowing and cultivating operations must be fully integrated and that careful sowing in straight rows is essential to good cultivation. It is probable that a considerable part of the cultivating difficulties experienced in 1943 might have been obviated by closer control of the sowing operation and by proper adjustment of the cultivating attachments.

Zehngraff (45p) comments that most of the attachments used for cultivating were originally designed for larger and more vigorous farm crops than kok-saghyz and that they are somewhat too heavy for kok-saghyz. Counts made by Zehngraff indicated as high as 10 percent loss from poor cultivation in the average field.

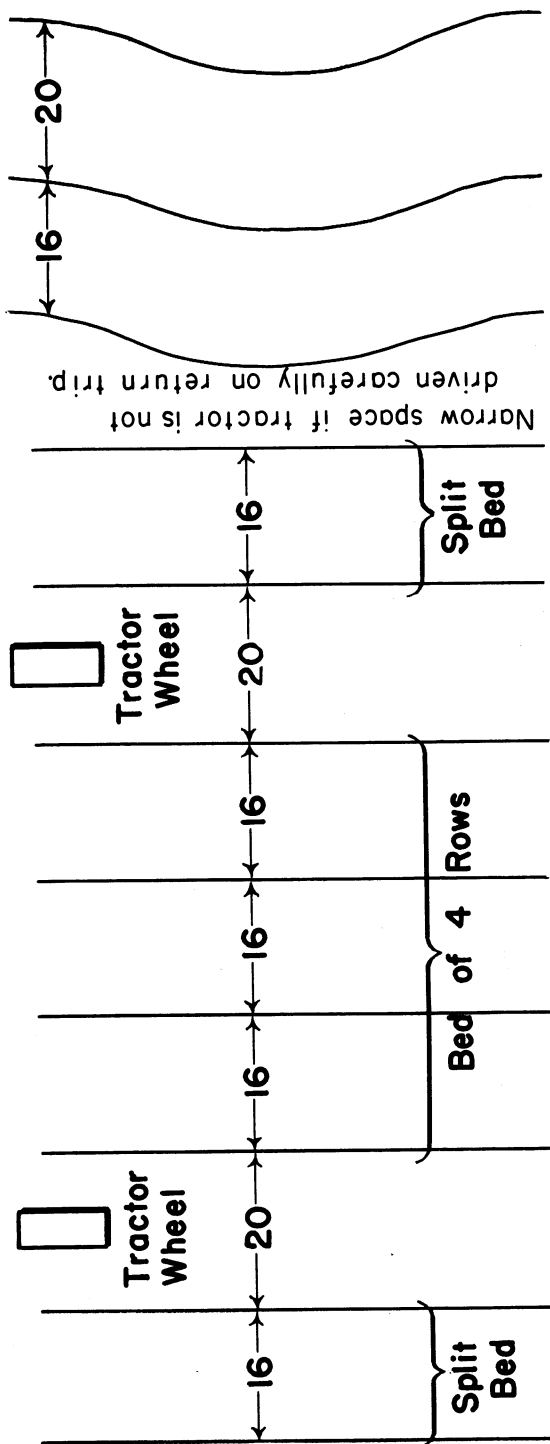


FIGURE 10.—Diagram showing spacing of rows as sown by tractor-attached multiple drill. With each trip across a field, one complete bed and two half beds are sown.

Oliver (31*p*) reports difficulty in cultivating even four rows at a time with the Farmall "H" tractor and the attached cultivating equipment because of rolling and unevenness of the fields. In the heavier soil of the Rogers tract clods fell on the plants even where a 3½-inch space on either side of the row was left uncultivated.

At Plainfield, Wis., the contractor's cultivating equipment was set up to cultivate rows spaced at 14 inches and, since it was in almost constant use on the contractor's large acreage of carrots and onions, there was little opportunity to secure a tractor-cultivator and take the time to adjust the spacing of tools to the 16-inch kok-saghyz spacing. Seeding had been done on a 4-row basis. Only one cultivation using a Ford-Ferguson tractor and 4-row cultivator was completed. Hand cultivators of the rotary-wheel type were relied on for the balance of the cultivating. However, these cultivators were only 9½ inches wide and left a rather wide space to be hand weeded. Green (15*p*) felt that a "straddle row" cultivator would have been more satisfactory since, with a careful operator, the cultivating teeth or weeding knives could have been spaced closer to the row and thus have eliminated one-half to two-thirds of the hand weeding.

Hand cultivators were used occasionally in Minnesota when it was not possible, because of wet soil conditions, to get on the land with a tractor. Milnes (28*p*), Oliver, and Joslyn (31*p*) and others, likewise made some use of hand cultivators. Hand cultivators, properly constructed and adjustable, and carefully used, may have a place in kok-saghyz culture, especially for initial work when the plants are small.

In Vermont a small self-propelled 2-row garden tractor with cultivator attachments was used. The wheel-spacing was somewhat narrow for the 16-inch row spacing adopted but otherwise Joslyn (31*p*) reports satisfactory results with this equipment.

Anderson (1*p*) rented a garden cultivator for the Aitkin, Minn., peat area. The motor did not have sufficient power for deep cultivation on the raw peat but it did a good job of weed removal and could be operated close to the rows. The Farmall "H" tractor which was equipped with cultivator bars and attachments and with steel rims and lugs was somewhat heavy for good work on moist peat soils. At times the soil was so wet that the tractor wheels pushed large segments of the row out of alignment. Anderson recommends a four-row rather than an eight-row set-up on peat soils and a lighter tractor with rubber tires would undoubtedly have been better.

Coster (6*p*) reports no difficulty in operating the tractor-cultivators in the irrigated section of Montana, particularly after the tractors

were equipped with rubber tires. The single-row spacing was 20 inches, and double and triple rows with 24-inch free space between beds were also tried out. Coster found it possible to use a single diamond point for cultivating and weeding between the double rows 9 inches apart, thus greatly reducing the weeding cost of the double-row beds as compared with the three-row set-up in which it was not possible to use the cultivator teeth. Coster not only accomplished efficient cultivation with the tractor-cultivator but also completed the ground preparation for furrow irrigation at the same time with irrigating shovels attached to the rear bar. Row cultivation destroys the irrigating furrows and they must be reconstructed after each cultivation.

Dent (*9p*) at Klamath Falls, Oreg., found it difficult to operate the tractor-cultivator on rather loose mineral soils and peat until after the implement had been equipped with rubber tires. Except with careful operation there was a tendency to uproot and destroy parts of the rows, or to cover them with soil. Metal shields were attached so as to overcome most of the latter difficulty. Both Coster and Dent used hand cultivators to advantage.

As indicated in Russian publications on kok-saghyz the number of cultivations required varied from three to eight depending on type of soil, number of weeds, distribution of moisture, timing and effectiveness of cultivation, and the compaction of the soil by seed picking and other operations.

In August 1943 whole fields of plants in the Red River Valley of Minnesota developed a sickly, chlorotic appearance. It was suggested that this condition might be due to an iron deficiency in the soil and tests were arranged to determine the cause. Local farmers claimed it was an unusual condition and some supposed that it resulted from a lack of aeration in the soil, aggravated by excessive spring moisture and by soil compaction. Recognizing that oxygen is necessary for good growth, it was decided to aerate the soil to see if the plants would recover. Deep cultivation, to a depth of 5 to 6 inches was resorted to in some of these fields where the soil, because of frequent and heavy rains, had become puddled. The diamond-point attachment was used for this purpose and was well suited for the job. It is unfortunate that no experiments were laid out or that no areas were left for comparison. The response appeared to be immediate and the plants regained their dark-green color in a few days. Deep cultivation was then used on all fields.

One particular area, the east half of the Art Skolness field at Moorhead, was wetter than the rest of the fields, and deep cultivation

could not be done until much later. A comparison of the root yield in this half of the field with that in the west half follows:

	<i>Number plants per foot</i>	<i>Average root weight (grams)</i>	<i>Yield per acre (pounds)</i>
West half—early deep cultivation.....	8. 1	5. 1	2, 798
East half—late deep cultivation.....	8. 3	2. 8	1, 579

That the root yield was only a little better than 50 percent in the east half was not altogether due to the lack of deep cultivation when needed. This half was a good deal wetter than the other half during the summer. Other cultivations as well as weeding were delayed.

In addition to need for aeration cracking and crusting of the surface soils of many areas often necessitated cultivation even when the weed growth was not heavy.

It is essential that sufficient equipment with adequate attachments be available to insure cultivation at the proper time. In 1943 some cultivating was done when, from the standpoint of the cultivating job, its effect on the soil, and the relative inefficiency of the weeding operation, the machinery might better have been standing idle. There was not enough equipment to do the full job between rains when the soil was in the proper condition. Cultivation is a comparatively simple, inexpensive operation and will save many times its cost by reducing hand weeding if it is accomplished at the proper time.

Weeding

Removal of weeds is necessary to reduce competition for plant food, moisture, and sunlight. Kok-saghyz cannot stand competition and is readily suppressed even when well established.

The intolerance of kok-saghyz to shade and competition with other species was demonstrated on a field near the Cass Lake, Minn., nursery in 1943. About 1 acre was sown to kok-saghyz in the spring of 1942 and produced an excellent stand. The winter losses during the first year were insignificant, not over 1 percent, and the condition of the stand during the second spring and early summer was good. Because of the labor shortage, no weeding was done the second summer and the area became overgrown with rank weeds. When the plot was examined in October 1943, not more than 1 percent of the kok-saghyz plants had survived the competition (45*p*).

At the Cass Lake and Lydick nurseries, on the other hand, kok-saghyz stands of the same age were kept clean of weeds and no losses took place during the second summer.

McQueen (27*p*) shows that a well-stocked stand of 1-year-old plants in the Minnesota nurseries was greatly reduced simply by being left unweeded for the season.

In several fields sown in 1943, poor growth and low yields resulted from late weeding and the consequent severe competition in the early growth stages of the planting. The most striking examples are the A. Thureen field at Crookston and the Art Skolness field at Moorhead (45*p*), figures for which are given in the following tabulation. Stand counts were made in October.

	<i>Seedlings per linear foot (number)</i>	<i>Average weight of fresh roots (grams)</i>	<i>Yield per acre (pounds)</i>
A. Thureen field:			
Early weeding -----	6. 8	8. 7	4, 006
Late weeding -----	4. 3	8. 8	2, 597
Art Skolness field:			
Early weeding -----	8. 1	5. 1	2, 298
Late weeding -----	8. 3	2. 8	1, 579

Stands from which seed is to be collected must be kept free of weeds to avoid the collection of weed seed with kok-saghyz seed. In 1943, large-seeded or rank growing weeds clogged and otherwise damaged the seed collecting equipment. In Wisconsin Green (15*p*) reported difficulty in keeping the seed collector in operation because the suction picked up from between the rows dry weeds that clogged the air-intake screen. It later became necessary to rake the dry weeds off the field.

Where seed is not to be collected it may not be necessary to keep the fields entirely clean of weeds, except that in the rubber extraction process weed roots mixed with the kok-saghyz roots cannot be easily separated as they float with the rubber and thus contaminate the final product.

As the fields must be kept free of weeds from sowing until harvesting, weeding becomes a more or less continuous field operation. Weeding proved to be the most costly operation in the 1943 growing of kok-saghyz. Even with particular care used in the selection of fields to avoid weedy areas, careful land preparation, summer fallowing, and delayed sowing, it probably will always be a costly operation. Kok-saghyz makes little above-ground growth for the first 30 or 40 days after emergence and is a weak seedling during the period when most native weeds flourish.

The first machine cultivations for weed control leave a strip 2 or 3 inches wide on either side of the row as the small size and nature of the young kok-saghyz plants makes it impossible to run tractor-drawn cultivating equipment any closer. A 4- to 6-inch weeding strip is thus left on each row. In other words on 16-inch row spacing, it is necessary to hand weed, repeatedly, at least 25 percent of the total cultivated acreage.

Weeds should be pulled out by the roots or cut off well below the surface of the ground or they will reestablish themselves. Some form of hand-weeding tool facilitates and speeds up the work, especially where the soil is compact.

Bothersome weed species differ with localities but the most difficult ones to control are the grasses and the deep-rooted types. Grass roots must be completely removed at the time of land preparation. If this is not done, subsequent weeding only remove the new growth and keep the plant in check. After kok-saghyz has been sown, attempts to remove grasses or large-rooted weed species result in seriously disturbing or destroying the stands.

In 1943 the number of hand weeding varied from three, for late-sown fields, to a maximum of eight. Four complete weeding were necessary for most fields.

Inability to get on the wet fields to cultivate at the proper time and delays in completing the weeding job greatly increased the weed problems. In some cases whole fields had to be disked out and resown because of excessive weed growth. It was found necessary to employ one or two persons per acre as weeders during the peak of the weed growing season.

The manpower required for weeding in 1943 (fig. 11) was so great that the supply of labor available to the program was scarcely able to meet the demand. Reports vary as to the amount of weeding needed in connection with second-year stands. Coster (6*p*) says that in 1944 weeds averaged 55 per square foot on the fall-sown field, and only 27



FIGURE 11.—First hand weeding in Minnesota kok-saghyz field. (Forest Service—F-426646.)

per square foot on the spring planting. These figures compare with an average of 102 weeds per square foot on the same area in 1943.

Knutson (45*p*) and Coster (6*p*) agree that cultivation the first year (1943) did not bring great numbers of weed seed to the surface but where the soil was plowed or deeply stirred another heavy crop of weed seeds was germinated. Milnes (28*p*) reports the weed growth at Saginaw, Mich., on peat was practically as vigorous the second season as in 1943.

At Plainfield, Wis., in the spring of the second season, it was necessary to use rotary hand hoes between the rows four times before the plants closed the space between rows. At Miles City, Mont., the number of weeds in the second-year stands was reported to be about the same as in the first-year stands.

In the second-year stands where machine cultivation was done, only one operation was necessary up to June 30, 1944. The cost of cultivating was much lower on these fields as the rows could be followed readily and the spread of the rosettes shaded out many newly germinating weeds.

Some effort was made to control weeds by the use of chemicals, but without success. Kok-saghyz belongs to a group of plants toward the elimination of which the development of chemical weed killers has been directed.

In coniferous-tree nurseries dilute sulfuric acid treatment of seed-beds, used to control damping-off, also tends to reduce the number of weeds. An unsuccessful attempt was made to control weeds by using this chemical on a small area of kok-saghyz and along ditches near the Saginaw plantings. The kok-saghyz succumbed before the weeds (28*p*).

An experiment in weed killing with Sinox Spray was made at Klamath Falls, Oreg., in 1943. It was found that kok-saghyz was very susceptible to this spray. Metal shields about 30 inches long were placed on the spraying device in such a way as to keep the spray from directly hitting the plants. Even with this precaution the fine vapor from the sprayer remained in the air until the machine had moved forward, after which it settled on the kok-saghyz, killing the plants.

It is possible that a flame-thrower or torch might be used to kill weeds if the kok-saghyz plants could be protected with a shield, but this operation was not tried out. Such a shield must necessarily protect any weeds within at least an inch of the row and some hand weeding would still be necessary.

Coster (6*p*) used Atlacide successfully for killing weeds along irrigation ditches at Missoula, Mont. There is some possibility that excessive use of this chemical along ditches might result in a contami-

nated irrigation water supply although no detrimental effects were noted with the relatively small amounts used in 1942 and 1943.

Coster also used this chemical to kill persistent perennial weeds in one of the Missoula kok-saghyz fields in the summer of 1942 as part of the summer-fallow weed-control operation. The treated area was still toxic to kok-saghyz, as well as to weeds, in the spring of 1943 and kok-saghyz sown on the treated area in 1943 was a complete failure.

More attention to land selection, land preparation, time of sowing, and other cultural operations will undoubtedly result in a reduction of the seriousness of the weed problem with kok-saghyz. More attention to the development of mechanical and chemical weeding methods should further reduce the excessive cost of the operation. However, it is doubted that the weeding operation can be brought within reasonable bounds unless the kok-saghyz plant itself can be improved in such a way as to make it more vigorous and competitive, particularly during the first few weeks of its growth.

Roguing

By late August and early September 1942 it became apparent that there were several types of dandelions in the plantings which had been made earlier that year in Forest Service nurseries. Some of these plants were larger, stronger, and grew more rapidly than others. They flowered more profusely and produced more seed (40p).

It was known from a few references in Russian papers that Russian plantings were often contaminated with dandelions other than the true kok-saghyz and that such forms were usually more vigorous, larger, and more profusely flowering. On the basis of these references, it was assumed that these larger dandelions were low in rubber content, and an attempt was made to remove all such plants.

At about this time translations of other Russian reports were received which indicated that the seed of kok-saghyz collected in the "thickets" of wild plants, and from which parent-source the supply of seed shipped to this country had been produced, was badly contaminated with low rubber-yielding types. This contamination may have been due to the actual collection of seed of other species as well as to the fact that kok-saghyz crosses readily with other dandelions.

Koroleva (19) outlines a study conducted by herself, Lipschitz, and Shishkin in native stands and plantings. Nine non-rubber-bearing dandelion types were found and their distinguishing characteristics are given in detail.

Presence of these low rubber forms means not only reduced rubber yields from the harvested roots, but, in plantings from which seed is

harvested, an additional contamination of the seed supply, due to their generally greater vigor and seed producing capacity. The only solution is a rigorous roguing-out of such forms.

In plantings to be used for rubber production only, the presence of some low rubber types will not materially alter the rubber yield and roguing may be done less carefully, or perhaps omitted entirely. In plantings for seed production, it is imperative that the undesirable types be removed completely.

Russian publications stress roguing not because of the growing space occupied by the rogues or their comparative aggressiveness, but principally because their prolific seed production quickly lowers the purity of the kok-saghyz seed supply.

That Russian papers recommended removal of rogues whenever and wherever they occur in kok-saghyz fields can readily be understood when one considers that a seed supply collected during the summer of 1942 from an unrogued kok-saghyz planting at Cass Lake, Minn., containing but 1 percent rogues, showed about 80 percent rogues when sown in the fields in 1943 (45p). Prompt germination and vigorous growth of the particular rows sown with this seed at once aroused suspicion that there was a high percent of rogues present in the seed supply. On the small section of one field sown with this seed the slow growing kok-saghyz were suppressed by the vigorous growth of the rogues. The following figures give the results from sowing this 1942 Cass Lake seed collected from an unrogued stand:

	Rogues in untreated seed (percent)	Rogues in soaked seed (percent)
Ross field, Crookston	70. 4	67. 3
A. Skolness field, Moorhead	88. 4	82. 4
Gleason field, Aitkin	63. 6	.....

Three distinct types of rogues referred to as types 1, 2, and 3 were recognized in the fields early in the summer of 1943.

Rogue type 1 is a Russian species resembling *Taraxacum officinale* Weber, the common introduced dandelion of the United States (fig. 12). Four or possibly five variations of this type were present. It is a prolific seed bearer, flowers earlier than any other species, and during the first year produces flowers and seed until killed by hard frosts. The seed is grayish brown. Soon after emergence the leaves assume an upright position in which they remain during the greatest part of the first year, whereas kok-saghyz generally forms a prostrate rosette. Leaves are thin and less turgid than the thicker, fleshier, and more leathery leaves of kok-saghyz. The upper surface of the leaves is dull and dark green, whereas kok-saghyz leaves are more glossy and lighter bluish green. The margins of the broad paddlelike

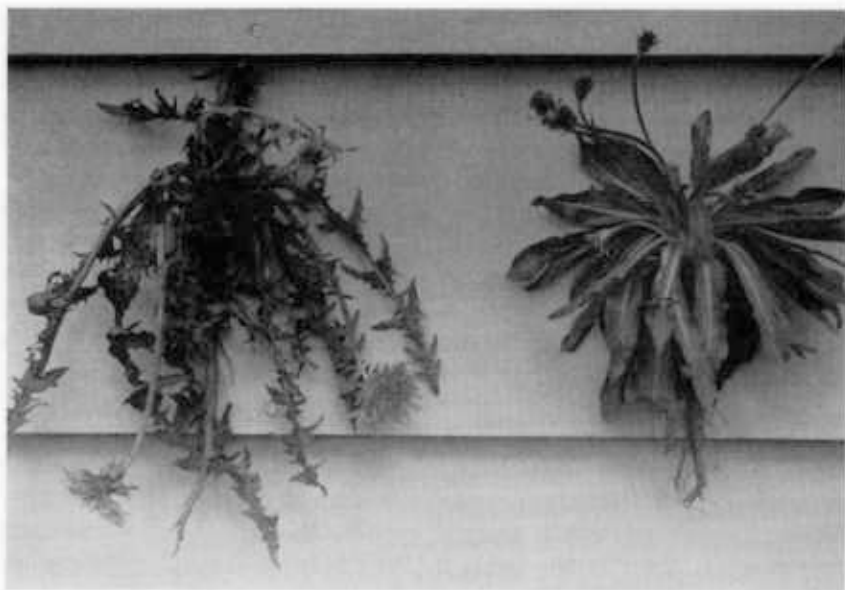


FIGURE 12.—Left, a non-rubber-bearing (rogue) dandelion; right, a typical kok-saghyz plant. (Zehngraff, Forest Service.)

leaves of the young plants are irregularly, shallowly, but sharply, dentate. The margins of the various forms of kok-saghyz leaves are lobed.

Rogue type 2 is a Russian species resembling *T. erythrospermum* Andr. At least three variations of this type were found in 1942 Minnesota plantings. It flowers comparatively late, beginning in August. During its first year it is not as prolific a seed bearer as type 1. It reaches its maximum seed production late in September and early in October. The reddish seed is easily distinguished from that of kok-saghyz. The leaves of this type lie flat on the ground but do not form as distinct a rosette as do those of kok-saghyz. Leaf texture is similar to that of type 1. The main vein of the lower part of the leaves is usually reddish where that of kok-saghyz is generally greenish yellow. The upper surface is dull and occasionally attains a reddish color. The leaf margin, even in young plants, is deeply and sharply indented.

Rogue type 3 is a Russian species not similar to any American dandelions. No variations were found. It is a rather prolific seed bearer, though not as prolific as type 1. It starts to flower at about the same time as kok-saghyz. The light gray seed has heavy barbs. The leaves lie flat on the ground and form a rosette as do those of kok-saghyz. This type is rather difficult to distinguish from kok-saghyz during the first 2 months because the leaf texture is quite

similar to that of kok-saghyz. The upper surface of the leaves is less glossy than that of kok-saghyz; the lower surface is distinctly gray and more leathery. The leaf margins are quite similar during the first 2 months to those of the lobed forms of kok-saghyz. The leaves are always longer than those of kok-saghyz. After about 2 months this rogue rapidly outgrows kok-saghyz and from then on it is easy to distinguish.

Rubber analyses of two separate sets of samples of the three rogue types compared with random samples of kok-saghyz gave the following results:

Rogues:	<i>Rubber content of sample taken July 24, 1943 (percent)</i>	<i>Rubber content of sample taken Aug. 27, 1943 (percent)</i>
Type 1.....	0. 20	0. 69
Type 2.....	. 20	. 34
Type 3.....	. 15	. 81
Kok-saghyz.....	2. 70	3. 90

Inasmuch as the development of a seed supply in anticipation of a future enlarged program was one of the objectives of the 1943 production tests roguing before any seed was collected was essential. Samples of the plants thought to be rogues and those plants supposed to be true kok-saghyz were tested for rubber content. The analyses proved the practicality of distinguishing the lowest rubber-bearing types on the basis of leaf characteristics, even in young plants. Accordingly, a set of simple instructions for roguing was prepared and distributed to all field personnel (42*p*).

Examination of seed produced in this country in 1942 (34*p*) disclosed two types of seed which appeared to differ from the seed of true kok-saghyz. One was a red seed, the other a much barbed type. Subsequent planting tests revealed these seeds to be of species recognized by the Russians as undesirable, low-yielding rogues. Other rogues do not have obvious seed characteristics which distinguish them from kok-saghyz.

The 1943 American seed examined showed a range of from 0.0 to 1.8 percent contamination with the identified rogue seed, the average being about 0.5 percent. Even if the undistinguishable rogue forms were present in a higher proportion it is doubted that total rogue content of the seed lot averaged much over 1 percent.

Faster germination, earlier emergence, and more vigorous growth of the rogues result in a much higher proportion of rogues among the growing plants than in the seed.

Unless rogues are eliminated, the proportion of them increases with each seed collection (fig. 13). Zehngraft (45*p*) conducted a series of studies which demonstrated that a 1 percent contamination of rogues in the seed grown without roguing resulted in a 38 percent rogue



FIGURE 13.—A section of a field showing four rows of kok-saghyz paralleled on each side by four rows of rogues. (Forest Service—F-426673.)

contamination in the seed harvested from these plantings. Use of such highly contaminated seed would result in practically complete elimination of kok-saghyz within a very few generations.

An experiment was conducted by Milnes (*28p*) at Saginaw, Mich. in cooperation with the A. T. Ferrell Company, makers of seed cleaning machinery, to determine whether rogue seed could be separated from kok-saghyz seed by screening or blowing. There was some indication that rogue seed is larger and heavier than that of kok-saghyz. A small amount of known rogue seed was dyed and thoroughly mixed with kok-saghyz seed. Several types of screens and velocities of air current were tried without success. Because of the similarity in size and general appearance of kok-saghyz seed to that of low-rubber dandelions there seems to be no way of mechanically eliminating the undesirable seed.

Obviously, the best way of insuring a rogue-free seed supply is to collect seed only from known rogue-free stands. It is not only essential that stands be thoroughly rogued before any seed is collected but, if stands are to be held over for a second year of seed collection, roguing should be continued. Coster (*7p*) found a number of rogue

seedlings the second season in plantings which had been thoroughly rogued the previous year.

Late-appearing rogues may result from secondary seed introduction from nearby native dandelions, from delayed germination in the original sowing, from self-seeding by rogues before elimination, from regeneration of rogue roots which were cut off too close to the surface, or possibly from the "throwing" by kok-saghyz of an occasional rogue type.

Roguing in actively growing stands is a simple process when the distinguishing characteristics of the rogues are known. A hand tool similar to the ordinary dandelion spud, which proved somewhat light for heavy soils, was made by flattening one end of a steel rod (fig. 14). A V-shaped notch was cut into the flat end and the tool sharpened. The leaves of the rogue are lifted to expose the crown and root, and the sharpened end of the tool pushed into the ground at an angle so as to cut the root 2 to 4 inches below the surface.

Apparently a satisfactory roguing job was done in most instances, but it developed that many of the rogues had been cut off too close



FIGURE 14.—Girl holding a rogue-type dandelion and a roguing tool used in Minnesota. (Forest Service—F-426679.)

to the surface. The portion of the root in the ground healed over and produced as many as 12 new tops.

At Burlington, Vt., the great numbers of rogues in the field grew so rapidly that they took over the stands from the beginning. The uniformity of growth was so great that the field gave the appearance of being either all kok-saghyz or all rogues. The seed sown at Burlington was all from one sack, none of which had been sown elsewhere. Apparently this sack contained a much higher proportion of rogue seed than other lots. It was assumed that the stand was all kok-saghyz so no roguing was done on this field. Inspection on October 1 showed that the entire field, except for 0.4 of an acre which had been seeded late, was practically 100 percent rogues. However, on digging samples it was found that from 10 to 15 kok-saghyz roots were actually present per linear foot of row. The vigorous growth of the rogues had suppressed the kok-saghyz and the tops were dead but the roots were still alive. While the rogue roots were $\frac{1}{4}$ inch or more in diameter, the suppressed kok-saghyz roots were $\frac{1}{8}$ inch or less and only from 3 to 5 inches in length. Analysis of a sample harvest indicated that all the larger plants were rogues.

While emphasis has been placed on roguing to insure a seed supply free from seed of undesirable inferior types, roguing may also be necessary to secure the most satisfactory rubber extraction. A large proportion of one shipment of spring harvested roots from Saginaw, Mich., to the pilot plant was apparently made up of rogues. These roots were woody, did not "cook" or break down well in the ball-milling operation, and were otherwise difficult to handle.

In any future kok-saghyz experimental work it should be recognized that roguing is essential for both seed and rubber production unless it is found that the extraction process can be modified in some way so that the inclusion of the woody rogue roots will not interfere with extraction of rubber.

In actual practice, roguing needs to include more than the removal of the rank-growing, low-yielding types. To insure uniformity, and thus ease and economy of seed collection and other cultural operations, it would be desirable also to remove small, weak, and otherwise undesirable plants. Such intensive roguing would probably not be justifiable in plantings for rubber production only.

The evidence at hand indicates clearly that either there is a great range in rubber content within the true type of *T. kok-saghyz* or that there are other low-rubber-bearing forms not easily distinguishable from kok-saghyz on the basis of the leaf and other characteristics used to classify the so-called rogues. As a result, roguing may be expected to produce only limited improvement in rubber yields unless

some method is found to fix the desirable characteristics and eliminate the undesirable ones.

Density, Spacing, and Thinning

One group of Russian kok-saghyz growers believes that the way to obtain satisfactory yields of kok-saghyz is to maintain dense stands of plants with rows spaced 16 to 18 inches apart. The other group believes that closer spacing of rows but thinning of the plants to about 4 inches within the rows gives equally good total yields, with better individual roots. The extra labor costs entailed in thinning are believed, by this group, to be compensated for by reduced labor requirements in harvesting the larger sized roots.

In view of these conflicting opinions, no generally applicable recommendation as to thinning practices for use in the initial American kok-saghyz trials was possible. In 1942, American plantings were variously thinned using single-plant thinning or "blocking" methods, or were left unthinned. Most plantings were made with rows at least 15 inches apart, wide enough for available cultivating equipment.

It was quite apparent that with some thinning of reasonably heavy stands there was an increase in average plant size but in most cases total yields were larger from well-stocked unthinned areas. Results of certain 1942 trials which illustrate influences of thinning on yields are given in table 7. Investigators almost invariably indicated excessive labor requirements in the thinning operations.

TABLE 7.—*Comparative results from thinned and unthinned kok-saghyz plantings at three locations*

Location and treatment	Planting date	Harvesting date	Calculated yield fresh roots per acre	Average weight per plant	Calculated rubber yield per acre
Windsor, Conn.:			<i>Pounds</i>	<i>Grams</i>	<i>Pounds</i>
Thinned to 3 inches.....	June 1, 1942	Nov. 8, 1942	4,711	9.3	38.1
Unthinned.....	do	do	4,379	2.3	23.8
St. Paul, Minn.:					
Thinned to 1½ to 2 inches.....	May 16, 1942	Oct. 29, 1942	5,359	13.5	41.4
Unthinned.....	do	do	8,013	7.6	60.9
Fargo, N. Dak.:					
Thinned to 3 inches.....	June 1, 1942	Oct. 20, 1942	¹ 3,332	-----	17.9
Unthinned.....	do	do	¹ 4,008	-----	24.7

¹ Root weights estimated at 44 percent of total plant weight; separate fresh root weights not recorded.

Based on the 1942 experience, 16-inch row spacing was adopted as standard for 1943. Equipment to handle eight rows at this spacing could be assembled on the longest available tractor-tool bar. It was necessary to provide wider space between beds or sets of rows at the width of the tractor gage to accommodate the tractor wheels. There-

fore, equipment on the tool bar was arranged in a center unit of four sets at 16-inch spacing flanked by outside units of two sets each at 16-inch spacing, but separated by 20 inches from the center unit (fig. 10, p. 69.)

A tractor-tool bar hitch was devised so that seed drills and cultivating tools would be constantly 16 inches apart. Compression springs held the drills on the ground and a chain lift was provided by which the drills could be raised off the ground when turning at the end of the field. Later it was found that a spacing bar was necessary to keep the individual seed-drill units from swerving off a straight line (32p).

In the West, under irrigation, row spacing had to be adjusted to permit furrow irrigation. In 1942, 16-inch spacing proved to be too narrow. Therefore, 20-inch spacing of rows was adopted in 1943 as standard at Missoula, Mont., and Klamath Falls, Oreg.

After a large part of the sowing had been done at Missoula it was discovered that the wheel spacing of the seed collector was not adapted to the 20-inch spacing. Therefore the sowing-spacing pattern was redesigned to accommodate the seed collector. Double rows, 9 inches apart, were sown by using seed drills side by side. A 24-inch space was left between the double rows.

Coster also tried a triple row arrangement with a 24-inch free space between the beds of triple rows. Three rows were seeded at one time by using a third seed drill centered behind two drills, thus leaving 4½ inches between rows.

One acre of rows 16 inches apart gives approximately 32,700 linear feet of row per acre. Spacing of single rows 20 inches apart gives some 26,000 linear feet of row per acre, while double-row spacing gives approximately 31,600 linear feet of row per acre, almost the same as that secured with the 16-inch row spacing. Triple-row sowing increases the linear footage to approximately 47,500 per acre.

Steinbauer (38p) reports results of a number of replicated rod-plot density-and-spacing studies made at various locations in 1943. While, for various reasons, the results of these studies in many cases did not yield data which could be applied without further investigation to field practice, they did reveal significant facts.

In the row-width and plant-spacing studies where row widths were varied from 8 to 20 inches and spacings of plants within rows from 2 to 6 inches, total root yields per acre were increased by greater plant densities whether these were occasioned by closer row spacings or by closer spacing of plants within rows. However, the increases in yields were not directly proportional to increased plant densities and reduced average-plant-sizes were shown with closer within-row spacings.

Row widths had less influence on average plant size than within-row spacings. No consistent influences of closeness of row or plant spacings on dry matter content or rubber content per plant were found.

Seed-production responses to varied spacings had approximately the same relationships as plant and root sizes, that is, a reduced yield per plant, but generally a greater total seed yield per unit area from the closer spacings, particularly when the increased plant densities resulted from closer spacing of plants within the rows.

In the comparisons of single-row culture with double- and triple-row types of arrangements (6 inches between rows in such double- or triple-row units, and 20 inches between outside rows of adjacent units) total yields of roots, rubber, and seed per unit area were increased as the number of rows per row-unit was increased or, in other words, as the total number of plants per unit area was increased.

Here again the increased total yields were not directly proportional to the increased plant densities; some reductions in plant sizes with consequent reduction in average root sizes, and seed yields per plant were found. No significant differences were found in the rubber percentage of roots from the different types of row culture.

In both of the spacing tests there was some evidence that plants which do not flower the first season are larger and have heavier roots than plants which flower the first season.

Studies (38*p*) conducted on 500 short-row samples with plant densities ranging from 1 to 28 plants per foot of row taken from 4 field-scale plantings of kok-saghyz on Bearden silt loam or silty clay loam soils in the Red River Valley of Minnesota demonstrated further that total yields of roots per acre are significantly increased with the increase in plant densities within rows up to the maximum used, and that these increases in total yields are accompanied by successive reductions in average root weight per plant with successively increased plant densities.

No significant alteration in the rubber content of root samples as a result of varied plant densities were proved, although average rubber percent for different density classes suggested a slightly increased rubber content from the more dense stands.

Trials with uniform row spacings but with plant densities within rows of 12 to 30 plants per foot of row on deep peat soil near Belle Glade, Fla., demonstrated that under winter growing conditions in the South the same general total yield, average plant size, and rubber content relationships are to be expected as when kok-saghyz is grown as a summer crop in the North. There was some evidence that seed production is slightly delayed with the denser plant stands but that the peak period of seed production is not changed by differences in plant densities.

On August 18, 1942, samplings were made at the Cass Lake Nursery to determine the effect of density of stand on size of roots (*40p*). Samples were taken in 12 different places where the soil was judged to be of about equal fertility and the only apparent variable in root yield was due to density of stands. The average weights by density classes are given in table 8.

Later information indicated a doubling of root weight from August 20 to October 5 and it is assumed that if taken at the end of the growing season, the August weights of the samples would have been at least doubled.

TABLE 8.—Average weight per root by density of stand at Cass Lake, Minn.¹

Average number of plants per foot of row	Average weight per root		Average number of plants per foot of row	Average weight per root	
	Fresh	Oven-dry		Fresh	Oven-dry
	<i>Grams</i>	<i>Grams</i>		<i>Grams</i>	<i>Grams</i>
3.....	2.10	0.50	40.....	0.50	0.10
5.....	1.65	.40	50.....	.40	.08
10.....	1.05	.25	60.....	.35	.08
15.....	.85	.20	70.....	.30	.07
20.....	.70	.15	80.....	.25	.06
25.....	.65	.13	90.....	.20	.06
30.....	.60	.12	100.....	.15	.05

¹ Seed sown May 28; sampled on Aug. 18, 1942.

It appears from present limited knowledge that a density of 8 to 15 plants per foot from the initial sowing would produce high yields of seed and total root weight per acre with fairly large individual roots without thinning. Where the emphasis is on root production alone a density of 4 to 8 plants per foot is estimated to be more nearly practical, and would probably have to be obtained by thinning a heavier stand.

Various difficulties were encountered with the 16-inch spacing generally used in 1943 plantings. In the Red River Valley of Minnesota the farmers use an 18-inch row spacing for onions, sugar beets, and other root crops, and their cultivating machinery is adapted to that spacing. The cultivation of differently spaced row crops would require the frequent adjustment of equipment.

Zehngraff (*45p*) indicates that with the equipment available 16-inch row spacing was somewhat too close. He also suggests that the 20-inch allowance for tractor tread is insufficient for iron wheel tractor travel. If the tractors were equipped with rubber tires, the 20-inch spacing would probably be sufficient. Zehngraff points out that, in practical operation of a tractor-drawn eight-row seeder, some variation in the space between the second and third rows of the split beds is bound to occur (fig. 10, p. 69).

Milnes (28p) noted that 16-inch row spacing is not wide enough to avoid damage by laborers during weeding. Mexican laborers on the Saginaw, Mich., fields were accustomed to wider spacing of the sugar-beet rows.

Green (15p), working in a region where 14-inch row spacing was used for vegetable crops and where the equipment could not be readily adjusted to the 16-inch spacing, recommends 20-inch spacing. He recognizes that there is a reduction in yield at that spacing but predicates his recommendation on the practicality of covering more of the area with machine cultivation, thus requiring less hand weeding.

In Montana the 20-inch row spacing was adequate for furrow irrigation. Towards fall the plants narrowed the space between the rows and there was considerable damage to the plants during cultivation, preparation of irrigating furrows, and operation of the seed collectors. Coster (6p) reports that double rows, 9 inches apart, with 24-inch free space between double rows, proved satisfactory for all purposes.

It is recommended that in any future operation the row spacing adopted in any locality be in accordance with the availability of farm equipment in that locality. Where there is no problem of adjusting equipment, the 16-inch spacing appears satisfactory, as did also the double row spacing of 9 inches with 24-inch free space between double rows for irrigated sections.

Further study should be given to row and plant spacings in connection with seed production. It is possible that the extra weeding and cultivation of seed-producing plants sown in beds might be relatively insignificant, in view of the increased seed yields and lowered collection costs.

The evidence suggests that thinning is not warranted in stands having less than 40 plants per linear foot of row, a density that seems unlikely with ordinary sowing methods and average survival.

Lysenko (28) insists that thinning heavy stands is desirable and suggests that it be done in connection with the first hoeing. He recommends that the rows be blocked out to leave several plants in a space 3 to 4 centimeters (roughly 1 inch) long alternating with spaces of 10 centimeters. He contends that with this practice large size roots will be obtained and that, although the number of roots per hectare will be smaller in comparison with fields where such blocking is not practiced, crops will be larger. This practice is also recommended in *Agricultural Technique of Kok-saghyz* (49) but no actual test data are given.

On the basis of Stoeckeler's 1942 findings (40p) and because of the relatively high cost of thinning, instructions were issued that thinning on the 1943 plantings would not be attempted unless the number of plants exceeded 35 per foot of row.

A number of plots were sown at various densities and thinned to different degrees to determine the effect of density on seed, root, and rubber yields as well as on the cost of thinning. Zehngraff (45*p*) established replicated plots on three fields. In all cases, at the densities tested, the yield per acre decreased and the size of the individual roots increased as the density decreased.

Coster (6*p*) reports on a number of detailed studies made at Missoula, Mont., in 1943 to determine the effect of density on yields of roots and seed. He states that in these plots the root weight per unit area increased up to the maximum density tested in this case, 15 plants per linear foot. He points out this finding may apply only to the first season's growth and that it is possible that at the end of the second season the total root weight might be less in the denser stands than in the more open stands.

Coster also tried blocking and thinning by hand and thinning by cross-field cultivation with cultivator teeth and weeding knives so adjusted as to have a blocking effect. He reports that while the cost of the hand operation was excessive thinning with machinery might be done at a reasonable cost. Machine thinning cannot be done before the plants are at least 20 days old as the young plants are very susceptible to any disturbance of the soil, nor can the thinning be done successfully after the plants are about 40 days old since there will be a tendency for many of the disturbed plants to reestablish themselves.

Zehngraff (45*p*) reports a definite relation between methods of seed treatment, the density of the stand, and the amount of seed produced per acre for the entire season. For example, in 1943 trials presprouted seed produced 18 plants per foot from which were collected 13.4 pounds of seed per acre.

Soaking treatment gave a stand of 10.1 plants per foot, prechilling, 14.4. The amount of seed produced per acre was 12.6 pounds and 12.7 pounds, respectively. Untreated seed established only 3.9 plants per linear foot that yielded 9 pounds of seed per acre. The KNO_3 treatment gave 1.6 plants per linear foot and a seed yield of only 4 pounds per acre. All sowings were at the same rate.

Zehngraff summarizes the 1943 experiment on seeding rate and density with a statement that 20 plants per foot seems to be the most desirable density for seed production. In these tests, 3 pounds of seed per acre were sown. There are approximately one million seeds per pound and the germination averaged about 70 percent. This rate of sowing gave an average total of 96 seeds per linear foot, with 67 of them viable.

Using pretreated seed on reasonably well-prepared ground 10 to 12 plants per foot survived to the end of the season. About half of this number survived where the seedbed was less well prepared or the seed

sown too deeply, and up to twice this number where the soil was especially well prepared, the best seed treatment used, and the seed sown at the correct depth (fig. 15).

To obtain about 15 plants per foot at the end of the season it is necessary to sow about 3 pounds of properly pretreated seed per acre at the right depth in a well prepared seedbed. Under poor seeding conditions or in rough seedbeds the amount should be increased by 50 to 100 percent in order to obtain the desired density.



FIGURE 15.—Minnesota kok-saghyz field just before maturation of seed. (Forest Service—F-427175.)

It is concluded that thinning is not necessary unless stands are excessively dense, that is, more than about 35 plants per linear foot. This density was seldom secured in 1943. It is probable that roots from stands more dense than this would be so small as to increase the difficulty and cost of harvesting.

Vegetative Propagation

By the late 1930's the Russians (39) had recognized that the available kok-saghyz seed lots produced plants varying greatly in rubber content, root size, and other important characteristics. As a means of propagating desirable plants, they investigated reproduction by

crown and root cuttings. While Lysenko (27, 28) emphasized that the method had not been thoroughly tested in field experiments, he pointed out that it might be of value in getting the plants off to a good start and enable them to successfully compete with early spring weeds.

After a series of studies Mynbaev (39) concluded that kok-saghyz is well adapted to propagation by cuttings if they are made in the spring, from April to mid-June. Crown cuttings proved best since the plants established from these cuttings flowered earlier and produced more seed and larger roots. Cuttings planted in November were a failure as were also attempts at propagation by leaf cuttings. Lysenko and Mynbaev agreed that the pieces of roots or crown should be thoroughly callused in moist sand before planting in the field.

Preliminary tests at Beltsville, Md., and St. Paul, Minn., in 1942 indicated good growth from cuttings under greenhouse conditions. As a result of this confirmation of Russian experience a number of field tests were planned in the spring of 1943.

Kluender (21*p*) prepared cuttings at the Chittenden Nursery at Wellston, Mich., from roots shipped from Manistique, Mich., and from Belle Glade, Fla. Some 23,000 root cuttings and 3,000 crown cuttings were carefully prepared. Some were callused in sand at room temperature and others were carried through the temperature treatment recommended by H. A. Senn, Division of Botany, Central Experiment Station, Ottawa, Canada, namely, 1 to 2 weeks at 40° to 50° F. followed by 1 to 2 weeks at 60° to 80°. Kluender reported a high percentage of callusing with each treatment.

However, field conditions were too wet to permit planting the cuttings when they were ready and they were held for 10 to 17 days. During this period there was considerable growth of etiolated leaves on the crown cuttings and a heavy loss by rot occurred (fig. 16). When planted the leaves dried and although 10 percent of the crown cuttings recovered and produced new leaves by midsummer they were a complete loss. Not a single plant was developed from the root cuttings planted in peat soil at Saginaw, Mich., in the first week of June.

McQueen (27*p*) reports preparation of 130,000 root cuttings and 60,000 crown cuttings at Cass Lake, Minn. Dormant roots were dug from the 1942 field plantings, and the larger ones were used for cuttings. These cuttings were treated in a room iced for the first 2 weeks, then opened, aerated, and held at room temperature for 10 days.

It was not possible to plant these cuttings at the conclusion of the callusing treatment and they were held in moist sand without any attempt to reduce the temperatures below 40° F. After 17 days the crown cuttings had a top growth of about $\frac{3}{4}$ inch and small roots appeared on the callus (fig. 17). On May 28, 15,000 crown cuttings

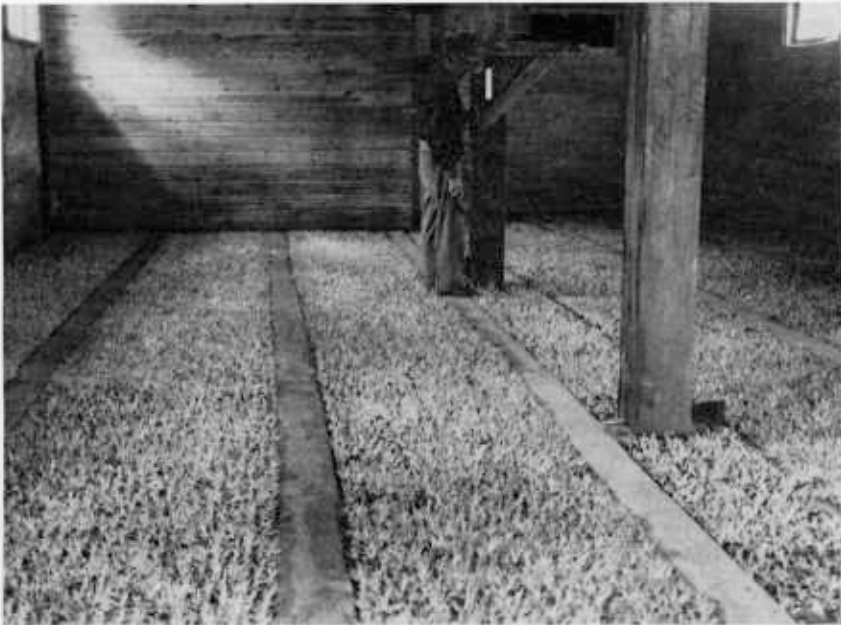


FIGURE 16.—Top growth on crown cuttings of kok-saghyz. At this stage these cuttings had not developed roots. (Forest Service—F-426663.)

were shipped to Crookston, followed by another 15,000 on June 2. By the time of shipment the leaves were about 4 inches long.

McQueen reports that the root cuttings callused well. Shipments were made to Crookston on May 26 and June 2. Aside from the top growth the cuttings were reported to be in good condition when shipped. Another shipment of root cuttings was made to Aitkin, Minn., on June 22.

Zehngraft (*45p*) reports that 3 months after planting only 5.1 percent of these crown cuttings and 8.2 percent of the root cuttings had become established. It is probable that had the cuttings been planted at the proper time greater survival would have resulted. Harvested roots from these plants were large and branched, and analysis showed high rubber content, comparable with 2-year-old seedlings. The plants from cuttings flowered more quickly and produced more seed per plant than plants from seed.

Coster (*6p*) planted about 1 acre of root and crown cuttings in early May 1943 at Missoula, Mont. The crown cuttings were planted in the field immediately without any attempt at callusing while the root cuttings were planted after 9 to 11 days in the moist-sand callusing medium. For a period of 2 weeks during and after planting the cuttings the weather was cold, 40° to 46° F., and 1.33 inches of rain fell. During this cold period the cuttings rotted in the ground.



FIGURE 17.—Upper row, crown cuttings. Lower row, root cuttings. Note the much more extensive top growth on the crown cuttings. (Forest Service—F-426664.)

Steinbauer (*36p*) reports good stands from cuttings planted in ground beds in the greenhouse but his plantings in the field at St. Paul did not survive. More satisfactory results were secured at Belle Glade, Fla., during the winter of 1943–44 using freshly callused cuttings from fall-dug Minnesota-grown roots which had been held in cold storage prior to shipment to Florida. Strong and Poehlman (*41p*) show 75 percent survival and establishment of the freshly made cuttings at Belle Glade. Higgins (*17p*) suggests that better results might be obtained in the North with fall-dug stock kept in cold storage until spring.

In order to test more adequately a lead developed in the summer of 1943, small plantings of crown cuttings and root cuttings were made at Moorhead and Aitkin, Minn., in the spring of 1944 using freshly dug roots and crowns as well as crowns cut in the previous fall in connection with the topping which was a part of root harvesting. In the mechanized topping operation, the knives occasionally cut too deeply and took off about 1 inch of crown with the tops.

These pieces, which had lain on the ground over winter were collected and planted in the fields.

In late June counts showed that 90 percent of the fall-topped crowns planted in mineral soil and on peat soil developed roots and tops. Ninety-three percent of the spring-cut crowns on mineral soil and 82 percent on peat had likewise established themselves.

Only 1 percent of the spring-made root cuttings had developed tops and roots by late June on either the mineral soil or the peat. An additional 76 percent of these cuttings were still alive on the mineral soil, and had developed small tops but no roots. Twenty-three percent of the cuttings on mineral soil and 99 percent of the cuttings on peat soil died.

Propagation by root or crown cuttings seems on the basis of existing data to be of value only in connection with plant improvement. If more information concerning the nature of root formation by cuttings, and particularly the effects of time-of-preparation and storage upon the rooting of cuttings, becomes available, it might be possible to mechanize procedures and make practicable the wide-scale use of cuttings.

The advantages of rapid and vigorous early development and uniformity of stands which might be expected with the use of cuttings as planting material would seem to warrant further investigation.

Transplanting

Since one of the goals of the kok-saghyz project was to prepare for the possible emergency production of rubber, consideration was given to all methods which might increase production of a given area in a season and to speed up improvement of the plant.

Along this line, a test was made of the practicality of transplanting seedlings, particularly with the thought that seedlings might be transplanted from the South to the North in the early spring, and from the North to the South in the early fall. By thus doubling the number of generations in a year plant improvement could be speeded and a seed supply built up more rapidly.

Transplanting proved more useful than cuttings in speeding production. In the spring of 1943 Zehngraft (45p) transplanted small plants from the 1942 harvest segregated at the time the root cuttings were made. Unfortunately, like the crown and root cuttings, the transplants had to be held for a long period before the fields were dry enough to plant. The temperature at which they were held was not sufficiently low and there was considerable top growth with accompanying root growth, hence abnormal development of the plants. Although the material was culled carefully, no transplants survived.

The experiment was repeated using freshly dug roots which, however, had grown and developed foliage. Unfortunately these, too, had to be held for several days because of rain and only 5.4 percent survived. On the Aitkin peat area the same late-lifted stock was transplanted immediately. There was a 75 percent survival where the planting was done by hand but only a 38.3 percent survival where the planting was done with a celery transplanting machine.

Zehngraft repeated the experiment using dormant stock in the spring of 1944 and secured survival of 96 and 97 percent respectively on mineral and peat soils.

Kluender (21*p*) likewise reports poor results at Manistique, Mich., in transplanting 1-year-old stock which had been held in cold storage for more than 1 month. The stock shipped from Belle Glade, Fla., in a refrigerator car gave better results.

Poorly developed seedlings from the 1942 planting at Savenac Nursery, Mont., were dug in the spring of 1943, trucked to Missoula, and immediately transplanted (6*p*). A fine stand resulted. Seed collection was started on June 18 and continued until mid-October. This was rather surprising since it was supposed that 2-year-old plants produce seed profusely for about 30 days in early summer and then go into a dormant stage. The root yield was calculated to be at the rate of 3,532 pounds per acre, a yield which lacked only 300 pounds of being as heavy as that from the best 1-year-old field at Missoula. The density of the surviving transplants was 4 per linear foot as compared to 12 plants for the seedling stand.

Higgins (17*p*) indicates excellent success at Geneva, N. Y., in 1943 with plants shipped from Belle Glade, Fla., and Tifton, Ga., even though the roots had been kept in cold storage from April to June at a temperature of 32° to 34° F. These transplants started growing almost immediately and yielded seed calculated at the rate of about 32 pounds per acre. Plants from seed sown on the same date as the transplants yielded 4 to 8 pounds per acre.

Apparently transplanting of seedlings to accomplish the production of two generations in 1 year presents no major problems. However, the expense involved is so great that it is doubtful whether any wide-scale use of transplanting would ever be made except in relation to acceleration of plant improvement.

Diseases of Kok-saghyz and Their Control

In the spring of 1942 the most serious disease of kok-saghyz was damping-off. At the Butternut Nursery, Butternut, Wis., most of the stand was wiped out by this disease.

The appearance of damping-off and experience with other introduced crops suggested the advisability of careful checks of kok-saghyz

plantings to determine whether or not the plant is susceptible to any native diseases and whether any diseases were introduced with it. These observations indicate that while kok-saghyz is susceptible to attack by fungi, bacteria, and viruses, these have not been the limiting factors in its production. Diseases have been observed, however, wherever kok-saghyz has been grown.

Rots constituted the principal reason for the failure of root cuttings in 1943 while poor stands from seed have been attributed mostly to unfavorable weather conditions. Considerable damage was also caused by damping-off, particularly pre-emergence damping-off.

There is a tendency for kok-saghyz plants, especially second-year plants, to become dormant during the summer under certain conditions, and apparently they are very susceptible to crown and root rots during this dormancy.

Specimens of diseased materials were collected from most kok-saghyz trial areas of the United States and Canada. Isolations of pathogenic organisms from these specimens were studied either by local pathologists or more intensively at the Rubber Plant Field Laboratory of the Bureau of Plant Industry, Soils, and Agricultural Engineering, St. Paul, Minn. (16p, 36p). These organisms included species of *Rhizoctonia*, *Fusarium*, *Pythium*, *Sclerotium*, *Sclerotinia*, *Botrytis*, *Ramularia*, *Alternaria*, *Phoma*; *Erwinia caratovora*, *Agrobacterium tumefaciens*; and *Xanthomonas* sp.

Disease-producing fungi and other organisms may be carried on and in the seed and are capable of preventing germination or attacking the seedlings, either destroying them or retarding their development. Fortunately all of the lots of Russian seed received in this country were relatively free from such organisms, a condition which has not, however, been true of some of the seed lots produced in the United States.

Extensive petri plate tests were made of all seed lots from Russia and many of the lots produced in the United States. A species of *Fusarium* was the most common pathogen isolated from Russian seed-lots in these tests and usually less than 3 percent of the seeds were infected with this fungus. Considerably more of the small amount of American-grown seed produced in 1942 was infected. Infection ran from 6 to 55 percent. In 1943 seed produced under very dry western conditions showed very little infection while that produced under the more humid conditions in other areas showed relatively high incidence of infected seed.

Thirty different fungicides have been tested in the field and greenhouse. On the basis of all tests Metrox (purple cuprous oxide) proved the best. Copper carbonate also was very satisfactory. Both of these fungicides not only cause significant increases in emer-

gence from infested seed but also reduce postemergence damping-off, thus increasing the net stand.

Seed treated with either of these fungicides may be subsequently vernalized or subjected to various other wet treatments without injury. Certain other fungicides such as New Improved Ceresan, Dubay 1452-C, Ceresan, Sanoseed, K-221, and U. S. Rubber No. 604 caused injury under some of the test conditions.

The first 2 or 3 weeks after emergence is a critical period in the life of the seedlings. If conditions are unfavorable for rapid growth, high percentages of the seedlings may damp-off.

In 1943 the losses from damping-off were negligible except on the peat soil at Aitkin, Minn., where mortality ranged from 31.4 percent on the previously cultivated peat soil to a much higher percentage on uncultivated peat. Species of *Pythium*, *Fusarium*, and *Rhizoctonia* were the fungi most commonly associated with seedling diseases.

From the time the plants reach the rosette stage up to the time they approach dormancy (either summer or winter dormancy), they are less likely to be damaged by diseases than at any other period because this is ordinarily a time of vigorous growth and development. The plants are, however, susceptible to leaf spots and virus diseases. Leaf spots are common but have been of little significance. They are caused by species of *Ramularia* and *Alternaria*, and various bacteria.

In the callusing trays, in transit, in various storage places, and in the soil, rots destroyed more than 85 percent of all root cuttings made in 1943.

Prevention seems to be the only control measure for these rots. Nothing has been found which will save cuttings once they have begun to rot. A number of fungicidal dips and dusts as well as chlorine dioxide and ozone gases have been tried without success. Preliminary studies indicate that much of the rotting can be avoided. There is good evidence that the stage of development of the roots when the cuttings are made is extremely important. In general, vigorous roots give the most vigorous cuttings. Striking differences in the ability of cuttings to regenerate and resist rots have been observed. Root cuttings made from plants that had just gone into dormancy following the peak of seed production were found to have a much higher mortality than cuttings made from plants that were growing vigorously.

Roots should be hardened and stored at low temperatures as soon as they are dug to prevent rots from starting. It is much safer to ship roots than cuttings.

Sanitation is of extreme importance. Storage rooms, callusing trays, packing materials, etc., should be kept free from pathogenic organisms.

Diseased roots should be carefully eliminated at time of digging. The less roots are handled after they are placed in storage, the better as rots are readily spread from diseased to healthy roots.

A number of plants scattered throughout the Red River Valley fields that developed a peculiar yellow condition in August 1943, and were later treated by deep cultivation, remained chlorotic. It was apparent that these plants were infected with some disease. The inner leaves of the rosettes were yellow and curled and the flowers and scapes were conspicuously distorted. Pathologists thought this to be an aster-yellows disease although it was not positively identified as such. The disease was distributed throughout the fields but affected only a few plants.

During the summer of 1942 a few plants were lost from root rot. In 1943 there was a limited amount of rot in several fields throughout the area, and it increased somewhat on mineral soils in the spring of 1944.

Peat soils appeared favorable to the development of rot organisms. The peat field at Klamath Falls was flooded during the winter of 1943-44 and the entire root crop was lost to rot. On the Plainfield, Wis., peat 4.7 percent of the roots were completely rotted in the spring of 1944 while an additional 21.3 percent were rotted down about 3 inches. The last examination was made early in the spring and it is probable that subsequently all roots showing rot would have become a total loss.

Heavier losses were noted in low spots where moisture was greatest and the incidence of rot seemed to be related to the lack of snow cover. Barton (3p) could detect no appreciable difference in the loss of roots which had been topped the previous fall and those which had not been topped. Kluender (23p), however, reports that 17 percent of the plants at Saginaw, Mich., topped but not dug in the fall of 1943 showed rot. Untopped plants showed only about 1 to 4.5 percent loss. Coster (6p) reports a small amount of rot in the 1-year-old stock carried over winter at Missoula, but a relatively heavy loss in the 1942 stock carried over to the third growing season.

In the Southern States kok-saghyz, as well as other crops, is often attacked by *Sclerotium rolfsii*, an important pathogen which is not a problem in the North.

Bair, of the Everglades Agricultural Experiment Station at Belle Glade, Fla., indicated that rot increased rapidly with hot weather in 1943 and that all of the true kok-saghyz roots in a small plot rotted during the summer. Most of the rogues in the stand remained in good condition throughout the summer dormant season and grew thriftily the second winter.

Erambert (13p) reports that root rot showed up on peat soils at

Belle Glade, Fla., as early as March 18, 1944, and that it had increased somewhat by the last of April.

Over-winter losses in the fields were confined almost entirely to root rot. On mineral soil the loss from rot in 1943-1944 was not over 1 to 2 percent. However, excluding the complete loss from flooding and subsequent rot on the Klamath Falls peat field, losses on peat fields ranged from 15 to 26 percent.

In Montana, Coster (7*p*) had sown seed at 2-week intervals from July through October 13, 1943, and forced early germination by irrigation. Sowings made prior to September showed no particular winter injury, but the sowing made on September 6 showed a loss of 3.29 percent. On the other hand, Oliver (31*p*) reported rather heavy losses in younger plants from a late reseeding on the Pease field at Seneca Falls, N. Y., in the latter part of June. Coster also reports that two Montana chinook winds followed by cold weather occurred during the winter and a number of ice ponds formed in the fields. The over-winter losses were no heavier here than in other parts of the fields.

Roots in storage are susceptible to the usual storage rots of root crops (36*p*). Serious rotting of the roots developed in the temporary stock piles at several fields and it became necessary to spread the roots out so that they might dry in the open air and sunshine.

A carload of fresh roots shipped from Moorhead, Minn., to the pilot plant at Philadelphia, Pa., in December 1943, apparently overheated en route, and about one-half of the shipment rotted. A test indicated that the quality of the rubber was not impaired by the rotting but the mass of rotten roots was difficult and unpleasant to handle.

Experience indicated that kok-saghyz is not subject to serious attacks by disease-producing organisms, except possibly root rot on peat soils after the first year. Nonetheless, it will probably be good agricultural practice to avoid following kok-saghyz with kok-saghyz, and to use some crop rotation. This practice will lessen the build-up of specific disease-producing organisms in the soil.

In plant selection and breeding work to increase root, rubber, and seed yields, attention should be given to the possibility of developing hardy plants and resistant strains. Further study of storage problems is essential to reduce rot losses, especially if the winter operation of the extraction plant is to be based on fresh roots.

Insects and Other Pests

In 1942 little insect damage was noted in the Lake States plantings. However, a heavy infestation of leafhoppers caused some concern at the Manistique, Mich., and Butternut, Wis., nurseries. A repellent

spray of Bordeaux mixture was used immediately and the subsequent damage was insignificant.

Root injury from white grubs was reported both in the Lake States and in Montana but it was not serious. In Montana some injury to seedheads was caused by red and black ants (5p). There was also a heavy infestation of grasshoppers for a period of about 5 days in the latter part of August. The insect population built up rather rapidly, but disappeared overnight and no control measures were undertaken.

In 1943 leafhoppers appeared in large numbers in some of the Red River Valley fields (24p), but were eliminated by unfavorable weather.

Grasshoppers were also present in sufficient numbers to cause damage. On the Lamb field at Moorhead, Minn., turkeys were moved close to the field and they rapidly eliminated the grasshoppers. The turkeys did some damage to the kok-saghyz before the roost was moved to a more distant point.

Coster (6p) reports a grasshopper invasion on one field at Missoula, Mont., from an adjacent field in early September 1943. Approximately 20 percent of one field was completely defoliated, but the roots sent up new leaves before the first of November. While the defoliation did not kill the 4-month-old plants, their development was delayed and the defoliated plants had not bloomed by June 20 the following year.

The most serious insect damage occurred in the winter of 1943-44 at Belle Glade, Fla., and Edinburg, Tex. At Belle Glade damage was caused by two species of cutworms. Cutworms are a real problem throughout the Everglades agricultural area and many vegetable producers find it necessary to spread poisoned bait continually. Erambert (13p) baited the kok-saghyz fields 19 times between December 16 and January 19. Damage was negligible after the rosettes reached a diameter of 3 to 4 inches. The surviving patches of older plants were dusted with arsenic as an added control measure.

Aphids appeared on the plants at Belle Glade in late December 1943, but did no appreciable damage and disappeared after a few days.

Some nematode injury has been noted in kok-saghyz planting in this country but it was not serious. Skabrilovich (59) reports kok-saghyz quite susceptible to nematode injury.

When seed collection started at Edinburg, Tex., in the spring of 1944 it was noted that nearly half of the seed heads were infested with a green worm later determined to be the larva of a small moth, *Homoeosoma electellum*. This moth laid its eggs in the flowers and the larvae fed on the seeds as they developed. Deffenbacher (12p) dusted the flowers with calcium arsenate. There was a reduction in

the infestation but it is not known definitely whether this was a result of dusting or whether the end of the insect's larval cycle had been reached.

Deffenbacher also reports fumigating the seed heads with carbon disulfide as they were collected. This insecticide has a deleterious effect on the germination of many seeds and probably is not to be recommended. This particular insect is reported to be distributed throughout the United States but has not appeared elsewhere on kok-saghyz.

Although, except for the two heavy infestations in the South, insects did not prove troublesome in the growing seasons of 1942 and 1943 nor in the spring of 1944, it is possible that with large acreages in production there might be a considerable insect problem.

In a few fields minor damage was caused by rabbits, pocket gophers, and other small animals.

Eradication

Inasmuch as the attempts to cultivate kok-saghyz represented attempts to domesticate a wild plant, numerous fears were expressed that the plant might become a noxious weed. The fact that kok-saghyz is a dandelion and that the common dandelion is a serious pest in some parts of the country, particularly in lawns, tended to emphasize this possibility. Control and eradication of plants was given attention during the experimental production of kok-saghyz because of this possible weed factor and to avoid continued growth of the plant and competition with later crops planted on fields once sown to kok-saghyz.

None of the farmers in the Red River Valley of Minnesota expressed any fear that kok-saghyz would become a noxious weed in their fields. Where the fields were plowed and disked in the spring of 1944 in the process of terminating the kok-saghyz experimental program, practically all of the kok-saghyz plants were killed out.

In one field planted to corn a few kok-saghyz plants survived but it was anticipated that these would be killed by cultivation (fig. 18). One of the farmers did not plow or otherwise remove the kok-saghyz but simply cultivated and harrowed the field and then drilled in a crop of wheat. The kok-saghyz was not completely eradicated and the wheat growth on the kok-saghyz rows was less vigorous. However, by the end of June the wheat had completely outgrown the kok-saghyz and it appeared as if the kok-saghyz would be entirely suppressed. Rogue plants which had been purposely left in some sections of this field were more vigorous and produced a heavy seed crop in the wheat.



FIGURE 18.—Cornfield showing survival of some kok-saghyz. This field was planted to corn without any special attempt to eradicate kok-saghyz from the previous year. (Forest Service—F-430376.)

In the Red River Valley it was recommended that if kok-saghyz had not been harvested, fields should be plowed and disked before being planted to row or grain crops.

The mineral soil at Saginaw, Mich., was plowed and planted to navy beans. Observations late in the season indicated that the kok-saghyz plants had been practically eliminated. The peat, where roots had been harvested, was disked and harrowed before being planted to tomatoes or other crops. A few kok-saghyz plants showed up but these were easily eradicated by regular cultivation.

On one field planted to reed canary grass, kok-saghyz did not present any difficulty but weed seed in the soil did germinate. Observations were made on one small area in this field on which kok-saghyz had not been harvested. Here the kok-saghyz plants competed with the weeds until late spring of the second season and then died.

The part of the Plainfield, Wis., planting on peat which was not harvested and on which no eradication measures were taken was plowed on May 11 and sowed to onions on May 18, 1944. Up to the end of June a few kok-saghyz survived but these were easily removed in the weeding process.

In Montana the situation was somewhat different. There, most of the farmers seemed to fear that kok-saghyz would become another weed pest, like the Russian-thistle.

Coster (7*p*) tried to determine the best method of eradicating kok-saghyz. When the land was simply plowed upturned roots were left protruding. Disking the fields effected a thorough distribution of roots throughout the soil. The roots started growth and on the fields on which disking was done it was necessary to pick out the plants by hand. A week after such hand removal additional kok-saghyz showed up and a second hand clean-up was necessary.

Another field was double-disked at right angles and then plowed, but even then some plants grew. A third field was double-disked twice. The first double-disking was done at right angles to the rows and the second, diagonally across the rows. Plowing followed immediately and completely buried the roots. It was necessary to hand-pick very few roots from this area.

A fourth field was double-disked, first diagonally, and then, at right angles to the rows. Two days later it was plowed 8 inches deep. Between the disking and the plowing, the shredded and mutilated tops and root crowns had dried and wilted. On this field it was not necessary to hand-pick any roots, and eradication was considered 100 percent successful. Such a process is considered too expensive to be practical.

In addition to the eradication of kok-saghyz in the several fields in Montana, eradication by chemicals of volunteer kok-saghyz on embankments, along irrigation ditches, and in depressions was undertaken. After the chemicals were applied, rains fell, volunteer kok-saghyz again made its appearance, and a second treatment was necessary.

Flooding of the peat tract at Klamath Falls, Oreg., in the winter of 1943-44 destroyed all the kok-saghyz. Dill (10*p*) planned three eradication experiments on the mineral soil. The first field was plowed 10 inches deep and "rod" weeding was done with an especially designed weeder which is used extensively in the locality. This tool cut the roots and exposed them to the sun. Dill estimated that at least 99 percent of the plants were destroyed by this method. The second area was disked 5 inches deep and the rod weeder used. The exposed plants dried quickly and 95 percent were killed. The third area was double-disked only. This operation cut the plants and exposed most of the crowns to drying, but by this method eradication was only 75 percent efficient.

SEED PRODUCTION**Seed Formation**

As previously noted, the Russians report that flowering of kok-saghyz generally begins 60 to 70 days after sowing. Milnes (28*p*) indicates that in Michigan, the first flowers were noted 42 days after seeding but that profuse flowering was not noted until the fifty-second day. Zehngraff (45*p*) reports that in the Red River Valley of Minnesota a 60-day period elapsed between sowing and the appearance of the first flowers. He comments that late-sown fields produced little or no seed during the first season.

Knutson (24*p*) also comments that, in Minnesota, approximately 60 days elapsed between sowing and the appearance of flowers on early sown plants and indicates that a shorter period elapsed on those fields which were sown later.

Coster (6*p*) at Missoula, Mont., noted a decided difference in vigor and growth rate between stands from 1942 Montana-collected seed and those from Russian seed. At approximately 50 days after sowing flowers appeared on plants from Russian seed, while plants from Montana-collected seed had already developed mature seed. The first field at Missoula sown with Montana-collected seed on May 8 yielded mature seed on July 1, 1943.

At Miles City, Mont. (18*p*), a plot sown in the fall of 1942 produced seed by June 21, 1943, while a plot sown April 9 did not produce mature seed until July 15.

Zehngraff (45*p*) also points out that the kind of presowing treatment given seed seemed to have a marked effect on time of seed production. Strips on which presprouted seed had been sown produced flowers considerably earlier than those planted with seed from other treatments. Plantings made with prechilled seed flowered about a week later.

At Belle Glade, Fla. (13*p*), the first flowers were noted on the November 1943 sowing 56 days after seeding but it was not until February 20 that the plants from this sowing reached the height of flowering. Seed was produced in appreciable amounts over a 64-day period. From the January 1 sowing the first flowers appeared after about 50 days but the period of production extended only 37 days.

In the winter of 1943-44 at Edinburg, Tex., the first flowers did not appear until 90 days after sowing (12*p*), because of cold weather.

Experience indicated that in addition to the influence of inherited characteristics, time of flowering is determined by factors which affect time of germination and rate of growth. Predominant among these factors are the treatment of the seed prior to sowing, depth of sowing, weather conditions following sowing and during the early life of the plant, and the degree of maturity and vigor of the seed.

The Russians report that most of the pollination of kok-saghyz is done by insects and suggest that bees are the most important. Steinbauer (36*p*) conducted an interesting study, at St. Paul, Minn., on the value of bees in cross pollination. Two large screened enclosures were built over several short rows of kok-saghyz. When the plants were in flower a small hive of bees was placed in one of the enclosures while the other was kept free of insects. Well-filled seeds were produced only in the screened enclosure containing the bees.

Dent (9*p*) at Klamath Falls, Oreg., reported that during the early part of the season of 1943 less than 5 percent of the seed heads had filled seed. Six hives of bees were brought to the edge of the field, but the bees did not appear to work actively on the dandelion flowers. A few other insects were noticed. Regardless of the apparent lack of insect activity, more seeds were produced after the bees had been introduced.

At Missoula, Mont., a number of stands of bees were located within one-fourth mile of most of the kok-saghyz plantings. Much bee and other insect activity was noted throughout the fields and may have been a major factor in the large seed yields produced at that point. Hurtt (18*p*) reported an abundance of bees at Miles City, Mont., and a high percentage of fertile seed was produced.

On the other hand, the vigorous 1943 stands on peat at Plainfield, Wis., flowered profusely, but in cleaning the seed it was found that more than one-half were not filled. In the spring of 1944 second-year plants on this tract likewise produced few filled seeds. This particular area was somewhat isolated from other flowering crops and there were apparently few bees in the vicinity, either wild or in apiaries.

E. G. Stoeckeler in an experiment, the results of which have not been published, found that when he bagged flower heads to prevent pollination by insects, no fertile seeds were produced.

Koroleva (20) observed that kok-saghyz in wild stands does not flower the first year, but under cultivation the same wild seed produces plants, of which 20 to 30 percent flower the first year. She found that by sowing seed of the first flowering plants from a 1-year-old stand she could secure up to 50 percent first-year-flowering plants in the succeeding generation. In 1939, using seed of the fourth generation of 1-year-old stands, she secured 100 percent first-year-flowering plants.

The fact that only a portion of the plants flowered and produced seed the first year was noted generally by investigators in this country. It was also noted that among the plants which flowered the first year certain plants flowered early and other plants flowered later. At the start of investigations no reliable information was available regarding

correlation of flowering habit with leaf form and other obvious characteristics, or with rubber content.

Zehngraff (45*p*) made specific observations on leaf variation, flowering habit, and rubber content. He reached the general conclusion that the lowest rubber-yielding plants flower early during the first year and that seed collected from the early flowering plants would produce a relatively low rubber-yielding population.

Zehngraff did not find consistent correlation between leaf type and flowering habit. Coster (6*p*), at Missoula, Mont., noted in 1942 that only a portion of the plants flowered the first year. He found that the plants which did not flower the first year produced the largest roots, the greatest tonnage per acre, and had the highest rubber content.

Second-year plants at Miles City, Mont., started growth the last of March and the plants were in full flower by May 17, 1944. Seed collection was started May 27. At Missoula there was not enough seed for collection until after the first of June. In Minnesota a few flowers were found on plants on mineral soils in early May. They became quite numerous toward the end of the month, but the height of flowering was not reached until June 15.

On peat soil the first flowers appeared on May 15 at Saginaw, Mich., May 25 at Aitkin, Minn., and May 28 at Plainfield, Wis. The initiation of flowering and the length of the flowering period is influenced by the time of the warming up of the soil.

Rather unexpectedly, seed produced in Wisconsin during a period of mild October weather following a hard freeze in late September was of high quality.

Irrigation

Altukhov (2) indicates that kok-saghyz does well where the total precipitation is above 500 millimeters per year (19 to 20 inches), with enough rain in April and May to assure uniform and complete germination of seed and swift and easy emergence. He also indicates that there must be rain in July and September in order to assure proper growth and yield.

In the available Russian publications there are few discussions of irrigation and irrigation practices, although Altukhov mentions that on the semidesert soils kok-saghyz can be grown with proper agricultural techniques.

He indicates that with irrigation fertilizers should be spread at the bottom of the furrow before sowing to prevent concentration of salts in the upper layer of the soil. He also states that on irrigated land it is well to give several "forcing waters" to induce prompt and even germination of seed. He suggests eight or nine irrigations during the

growing season, spaced 15 to 20 days apart in the spring and fall and 10 to 12 days apart in July and August.

In the 1942 tests on light sandy soils of the Lake States Stoeckeler (40p) and Jones (19p) found that several irrigations were necessary to secure germination and maintain proper growing conditions, although the average annual precipitation at Cass Lake, Minn., is 22 inches and at Manistique, Mich., 30 inches. The rainfall during the growing season (April through October) averages 16 inches and 18 inches, respectively. Plantings on heavier loams and silt loams, more retentive of moisture, probably would not require supplemental water except in those years when the seasonal rainfall is less than average.

During the growing season of 1943 and the spring of 1944, excessive moisture rather than drought was an unfavorable factor in the Lake States and New York-Vermont areas.

In the West the availability of irrigation water is insurance against crop failure although in a few favorable localities dry-farming techniques have been developed.

In Montana (5p, 6p, 7p) irrigated lands were used for the larger production tests but an attempt was made to grow kok-saghyz at Lewistown, Mont., and Bonners Ferry, Idaho, by dry-farming methods. At Lewistown insufficient rainfall after sowing prevented any germination. At Bonners Ferry fair germination was secured but the plants did not develop sufficiently because of lack of moisture, and the planting failed.

Two systems of irrigation are used in Montana, flooding and furrow. In 1942 a 10-acre tract at Miles City was sown to kok-saghyz and flood irrigated. Severe crusting of the soils prevented satisfactory emergence. Later irrigation water carried a fine silt which was deposited on those plants that had emerged. This deposition was injurious and killed many of the small plants.

At Missoula row or furrow irrigation was used to better advantage. Consequently, in 1943 furrow irrigation was specified as standard practice. The regular furrow irrigating procedure in Montana is to level and float the entire field before sowing. Furrows are opened by irrigation shovels attached to the cultivator bar of the tractor. Water is then taken from the irrigation ditches through laterals to the fields.

Some of the Missoula fields are lightly rolling and to irrigate the rows it was necessary to put in an unusual number of laterals following the higher ridges or benches. A good head of water was necessary in the laterals, but it had to be reduced materially in the furrows to avoid erosion. Short lengths of 2-inch pipe were used to take water from the laterals to the furrows.

By careful control it was possible to irrigate most of the fields without causing erosion. It was impossible to avoid flooding in some of the

lower portions of the fields, but contrary to the experience at Miles City no damage from crusting was noticed. The water was clear most of the time and no silt was deposited on the plants.

In 1942, seven complete irrigations were given the Missoula fields, while in 1943 only four were required.

To determine the water requirements of the plants water was withheld from small areas. Areas which were naturally difficult to irrigate were selected and received no moisture except rainfall. In every case but one the kok-saghyz died. The one area on which kok-saghyz survived produced plants which failed to develop and flower properly.

At Miles City, in 1943, water was withheld until it was noted that the plants were wilting and about to die. Water was then applied. After this irrigation a number of the first-year plants entered summer dormancy. This experience confirmed the opinion of Neuman and Sosnovets (43) that drought and intense heating of leaves are factors in the induction of summer dormancy. These investigators suggest that summer dormancy is not a result of biological maturation but is due to unfavorable conditions of growth.

At Missoula, in 1944, it was necessary to irrigate second-year stands once during the spring period, but moisture conditions at Miles City made it possible to go through the spring there without irrigation.

At Klamath Falls, Oreg., irrigation water was not put in the ditches until the first of May, hence it was impossible to irrigate early April 1943 sowings (9p). A May sowing was lost when the irrigation canal broke and water was unavailable for several days at a critical period. After water was again available, the second-year stand was irrigated by flooding.

On the Klamath Falls mineral soil furrow irrigation was attempted, but because the tract had never been in cultivation and the soil did not settle well after leveling, difficulty was experienced in getting water distributed. This may have been one of the factors responsible for the light stands and the light seed crop. Crusting was also a factor but no attempt was made to control it by irrigation.

Coster (6p) observed that it is impracticable to operate the seed pickers across the lateral irrigation ditches which must be filled following irrigation and reconstructed when it becomes necessary to irrigate again.

Seed Collection and Yields

Inasmuch as building up of the seed supply was requisite to the development of the considerable acreage of kok-saghyz which the Russians had planted by 1940, attention had been given by them to problems of seed collection. Observations on the maturation of seed heads, and germination tests, had led the Russians to specify that the seed heads be collected just before they begin to expand into their

typical globular shape and just as the white pappus begins to appear above the bracts. At this stage the seeds themselves have become yellowish gray.

The Russians had found it necessary to pick over a planting several times a day to avoid loss of large amounts of seed, for maturation of the seed heads is, under proper conditions, very rapid. Altukhov (2) points out that first-season plantings require the services of 3 or 4 men per hectare (2.47 acres), and 2-year-old plantings 11 to 12 men per hectare each day during the entire seed-collecting season, which he reports as lasting 2 or 3 months on 1-year-old plantings and 1½ to 2 months on 2-year-old plantings.

The enormous expenditure of manpower involved in this operation had led the Russians to attempt development of machinery for seed collection, but as far as could be learned most seed collection in Russia was still done by hand as late as 1940.

Average Russian seed yields were reported as 20 to 30 kilograms (one kilogram equals 2.20 pounds) per hectare on first-year plantings and 80 to 100 kilograms per hectare on second-year plantings.

Seed production in the Lake States during 1942 was disappointingly low, an average of 1½ to 2 pounds per acre, or less than the amount of seed sown. All seed picking was done by hand, the plantings being gone over daily for a period of about 60 days.

Where hand-picking of seed is necessary it is important to know the proper stages for harvesting seed heads in order to obtain seed of good quality without losing too great a proportion of seed between pickings through action of wind or rain.

The 1942 tests indicated conclusively that good yields of seed or roots could not be secured on light, infertile soils of the northern forest area of the Lake States. A somewhat higher yield of seed was collected at Manistique, Mich., but at a greater expenditure of man-days. Better soil at the University Farm, St. Paul, Minn., produced 17.5 pounds on 0.7 acre.

Montana proved to be a much better seed-producing area. Coster (5p) reported that in 1942, 225.5 pounds were picked from 16½ acres, or an average of about 13 pounds per acre, on stands averaging less than one plant per linear foot of row. At Missoula, seed collection was done by hand between 10 a. m. and 7 p. m. daily. At first the area was covered three or four times a day, later twice daily.

It was realized that hand-picking could not be justified either from the standpoint of the labor requirements or the cost, and hence considerable work was done in the development of mechanical seed pickers.

Through cooperation of the Lake States Forest Experiment Station and the Minnesota Agricultural Experiment Station the following

guide was prepared for determining proper picking stages of seed heads to give maximum yields of viable seed (fig. 19):

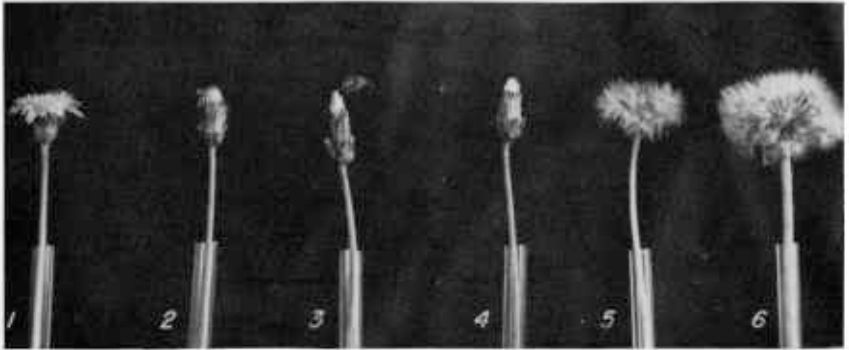


FIGURE 19.—Stages in the development of kok-saghyz flowers and seed. (Forest Service—F-422422.)

Stage No.	Description of the stage of development
1.	The yellow flower is fully opened.
2.	The flower has closed, with the tips of the yellow petals protruding above the involucral bracts. Pappus not visible.
3.	Seed head closed with dried yellow to brown corolla resting on top of visible white pappus. Remains of corolla can be pulled off readily. Seed still firmly attached.
4.	Remains of corolla sloughed off. Pappus protruding as white tuft above the urn-shaped to slightly spreading involucre. Seed adhering fairly firmly. This is the best stage to collect seed by hand.
5.	Seed heads partially open so that pappus forms a hemisphere. Seed comes loose with moderate pull but cannot be blown loose by light puff of wind. Hairs of each pappus are unfolded in shape of a small parachute. Seed should not be allowed to advance beyond this stage if it is hand-picked and if maximum recovery is desired.
6.	Seed head forming practically a full sphere. Involucral bracts reflexed. Seed readily detached by slight puff of wind. At this stage seed must be picked as often as twice a day to prevent loss by natural dispersal. This is the only stage at which highly efficient mechanical seed collection by suction devices appears feasible, although some seed in late stage 5 development may be detached with strong suction.

Lysenko (28) explains that the Russians had developed a seed-picking machine which could be readily assembled by a farmer in his shop. This machine was said to increase the efficiency of collection 15 times and to greatly reduce the trampling and compaction of the soil by large numbers of laborers engaged in daily hand picking.

In the winter of 1942-43 a blueprint of this machine was secured by the Farm Power and Machinery Division of the Bureau of Plant Industry, Soils, and Agricultural Engineering, and a machine was built and studied. In the late summer of 1942, Aamodt, of the Lake

States Forest Experiment Station, built a one-row, manually propelled seed picker, and when he found that the principle he had used was apparently satisfactory, he built a two-row motor-propelled picker. Stoeckeler (40p) describes these machines and the operation of them. The later-developed Ramp four-row pickers, with which most of the seed collection in the expanded program in 1943 was done, are described in the section of this report on equipment development.

In 1943 the seed yield on peat at Saginaw, Mich., averaged about 5 pounds per acre. In Minnesota a total of 1,041 pounds of seed was collected from the 228 acres on mineral soils in the Red River Valley, an average of about 5 pounds per acre. The individual fields varied from a low of 2.24 pounds to a high of 16.91 pounds per acre. The latter high yield was secured from a portion of a field which was sown on April 24 on Bearden silt loam and which represented perhaps the best stand in Minnesota. In Montana, Coster reported a collection of 1,218 pounds of seed from 31.16 acres, an average of about 40 pounds per acre.

In order to learn something of the theoretical yield, Zehngraft and Aamodt (46p) counted the number of buds and flowers on a given number of plants over a considerable period, determined the average number of seeds per flower (fig. 20), and computed a theoretical yield of over 200 pounds per acre for mineral soil fields of Minnesota.



FIGURE 20.—Close-up of kok-saghyz plants in flower. (Forest Service—F-430369.)

Hurt (18p) also computed a theoretical yield from the small plot at Miles City, Mont. He tallied all of the seed heads produced on sample plot areas during the period May 20 to June 15, 1943. He determined that the average head contains 100 seeds and that 95 percent of these were filled. His computation indicates, for the stock seeded in the fall of 1942, 265 pounds per acre from single rows of varying spacings, 255 pounds per acre from double rows, and 381 pounds per acre from triple rows.

Stock from seed sown in the spring of 1943 produced somewhat less, namely, 193 pounds from single rows, 177 pounds from double rows, and 360 pounds from the triple rows.

Obviously, these computed amounts of seed produced must be discounted to allow for seed dispersed by wind and rain.

Theoretical calculations of yield per acre based on collections from small samples or by determining the number of seed per seed head, the number of seed heads per plant, and the number of plants per acre are much higher than actual collections. The differences undoubtedly reflect both inadequacy of the samples and relative inefficiency of machine collection.

The limited 1944 experience in connection with second-year seed collection and yields was disappointing in all areas. The season was late because of a cold, wet spring, and because of the termination of the program all work had to be discontinued before the production season was half over. June proved to be an exceptionally rainy and windy month and the picking machines could be operated only a portion of the time. Further, rain and wind dispersed the seed. Rain and wet ground prevented picking 3 days out of 15 at Moorhead and Crookston, Minn.; 4 days out of 11 at Saginaw, Mich.; and 5 days out of 11 at Plainfield, Wis. Coster reports that June was the wettest at Missoula, Mont., since 1908. Here the machines could be used to pick only 9 days out of 22 and operation had to be suspended on some of the 9 days.

In all of the fields except at Klamath Falls, Oreg., second-year kok-saghyz made luxuriant growth and sent up flower scapes to a height of 18 to 24 inches. At Klamath Falls second-year stands compared closely with the best fields of 1-year stands at Missoula and in the Red River Valley.

The seed-picking machine which was developed in 1943 lacked suitable adjustment for height although it could be adjusted to some extent. Knutson (25p) reports that before the limited height adjustment was made the machine picked only 18 percent as much as was picked by hand and that after the machine had been raised as high as possible it picked 45 percent as much.

Milnes (29*p*) estimated that about 36 percent of the crop was harvested during the short period of operation at Saginaw. His actual collection was 8 pounds per acre.

Coster (7*p*) at Missoula recovered 19 pounds of clean seed per acre and calculated that it was about 40 percent of the seed produced during the period of collection. He estimated that if he had been able to collect seed throughout the entire period of production the collected yield would have amounted to 100 pounds per acre.

Coster retained four rows across the field which was sown in 1942 and carried through 1943 to the spring of 1944. In the third year this very thin stand had lost much of its vigor. The seed was hand-picked and yielded a calculated average of 8.33 pounds per acre. When this stand was 2 years old it averaged 115 pounds of seed per acre.

At Klamath Falls, rain fell on 9 out of 17 days in June 1944, but the machine picker was operated at least a portion of the time on 13 days. Although the stand was thought to be more or less of a failure in 1943 Dill (10*p*) collected seed at the rate of 15 pounds per acre. He estimated that this collection was about one-third of the seed produced during the period. The stand averaged only 2.2 plants per linear foot, and he figured that if there had been a full stand and collection had been made through the entire seed-production period without interference by rain there would have been a yield of 200 pounds per acre.

Strong and Poehlman (41*p*) compared seed yields in Florida in 1943-44 from plantings made with transplants, cuttings, and seed. Unfortunately their initial sowing was destroyed by cutworms and the plots were reseeded on December 28. An indicated yield of 22 pounds of seed per acre was secured from the seeded area with seed collection confined to the period of March 18 to April 6.

Transplants shipped to Florida from Minnesota, after having been held in cold storage for a short time, produced seed at the rate of 125 pounds per acre.

Material for cuttings was also shipped from Minnesota to Florida. Cuttings were made and planted directly without any attempt at callusing. Those planted between November 23 and December 6 produced stands which indicated a yield of 44.8 pounds of seed per acre while from those planted on December 23 the indicated yield was 32.6 pounds per acre.

Use of the seed-collecting machines in 1943 presented additional problems. When the tray of the seed-picking machine has been filled it must be removed and the seed transferred to a container. The seed with the pappus attached is very light and considerable losses occur unless care is taken in the transfer process. Coster (6*p*) made

large sacks which he slipped over the trays as they were pulled from the machine in the field.

The machines collected flowers, buds, immature seed heads, flower scapes, and dead leaves. On peat fields dry peat particles were drawn into the machine, as were dry mineral soil particles on some other fields (fig. 21).



FIGURE 21.—Front view of seed-collecting machine in operation at Saginaw, Mich. (Forest Service—F-427462.)

Green (*15p*), at Plainfield, Wis., found it necessary to rake and remove dried weeds to prevent their being drawn into the machine. He endeavored to reduce further the collection of extraneous material by controlling the amount of suction. By closing the fan opening he also deflected the dust away from the machine operator.

As noted, difficulty was encountered in 1943 because it was not possible to raise the seed pickers high enough to avoid collecting unopened seed heads, flowers, and scapes. This made it necessary to empty the seed trays frequently and increased the task of separating the seed from the debris. In 1944, increasing the height of the seed-picking machines, together with moister soil conditions eliminated the earlier difficulty of picking up dry soil and peat particles.

Seed Threshing and Cleaning

Russian papers on kok-saghyz contain few references to the methods employed in threshing and cleaning seed although it is noted (2, 49) that collected seed heads must be thoroughly dried and then rubbed against a screen to remove the pappus. Cleaning and grading are done on a "proper machine," not further described.

The 1942 experience in this country revealed that hand picking required much labor and that the seed heads had to be thoroughly dried and rubbed through a mesh screen before the seed was cleaned. In the drying process the seed heads had to be spread out thinly and stirred frequently to prevent molding.

As a part of the seed threshing and cleaning operation, it is first necessary to remove the flowers, immature seed heads, green leaves, and flower scapes. This operation is usually done either in the evening of the day of collection or the morning of the following day. Failure to remove this high moisture-holding or moisture-absorbing material from the seed increases the difficulty in separating the material and often in damage to the seed. Removal was accomplished by rubbing the mass of seed and debris over a 1-inch mesh chicken wire or $\frac{1}{2}$ -inch mesh hardware cloth nailed to a frame (fig. 22).



FIGURE 22.—Working kok-saghyz through screen to separate seeds from pappus, stems, and other refuse. (Forest Service—F-426939.)

The next step in the operation is to rub the seed over a 12- or 14-mesh screen to break the seed away from the pappus (fig. 23). The seed is then cleaned and screened in a fanning mill. Under proper conditions the whole operation of threshing and cleaning kok-saghyz seed presents few problems.

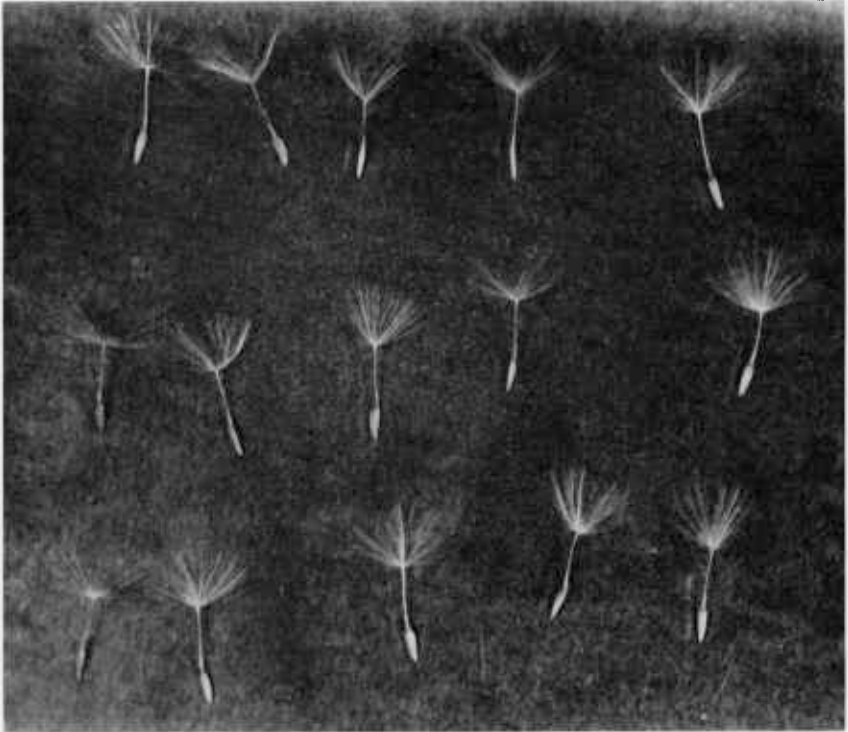


FIGURE 23.—Kok-saghyz seed showing pappus attached. (Forest Service—F-422437.)

In Montana, in the summer of 1943, the humidity was generally low and there was usually a light breeze. It was possible to separate the seed from the trash and to break the pappus away from the seed in a single operation by rubbing the entire mass over a 14-mesh screen. The screen, nailed to a suitable frame, was set on sawhorses about waist high. There was usually just enough breeze to carry away the pappus but not enough to carry the seed from a canvas spread on the ground directly under the mesh screen.

In the spring of 1944 conditions were much more humid, and it was necessary to thresh and clean the seed indoors. These two operations had to be separated. After removal of the trash the seed

was cleaned in the fanning mill. When the operation was conducted indoors the air was filled with floating particles of pappus, forcing the workers to use respirators and goggles.

In the Lake States the seed was never dry enough to separate from the pappus immediately after picking. It generally felt damp to the touch. The seed was separated from the trash on the morning of the day following picking; then, with the pappus attached, it had to be dried for a period of 7 to 10 days. After the warm period of the summer had passed heat had to be supplied to dry the seed.

Here again, as at Missoula, dry particles of pappus floated throughout the drying and threshing rooms making it dangerous for workers without goggles and respirators. This condition was recognized as being not only hazardous to the health of the people working in the room but also dangerous from the standpoint of fire or dust explosion. After the first few days of operation the large room was partitioned into two parts and all cleaning and threshing was done in the smaller room where an exhaust fan was installed.

Seed cleaning was done in standard cleaning mills of the clipper mill type, with various screen combinations and air pressures. The ease of cleaning kok-saghyz seed is determined by the amount and character of foreign material in the seed as it reaches the fanning mill.

As a general rule, little or no seed of plants other than kok-saghyz was collected by the seed-picking machines, although Green (15*p*) reports that some weed seed, along with dry leaves and small peat particles, were picked up at Plainfield. In the process of removing the pappus, some of the dried leaves were broken into small pieces of about the same size and weight of the kok-saghyz seed. It was very difficult to remove this material. Even though the seed was run through the mill many times with minor adjustments, in the end there was still foreign material mixed with the seed.

Knutson (24*p*) reports that dry mineral soil particles were picked up by the machines and that toward the end of the season some pigeon grass seed was collected. The soil particles were readily removed by the blower. A No. 16 screen was used with some success to separate the pigeongrass seed, but repeated cleanings were necessary and even then a few of the pigeon grass seeds remained.

An attempt to perfect the seed-cleaning process was made by Kluender in cooperation with the A. T. Ferrell Company at Saginaw, Mich. The extraneous material was not separated from the seed until after the entire mass had been thoroughly dried. After being dried the material was rubbed through $\frac{1}{2}$ -inch mesh hardware cloth, an attempt being made to avoid breaking the dried leaves, stems, etc. The seed with pappus attached and other fine material was then rubbed through 12-mesh wire cloth. During the rubbing process the

workers wore leather gloves or used heavy short-bristled cleaning brushes, small block-rubber squeegees, or medium-sized whisk brooms. The whisk brooms seemed to work best.

The same difficulty with floating particles, pieces of pappus, etc. was reported here as elsewhere. A tight ventilator was built leading up to an exhaust fan in one of the windows of the building. This aided greatly in keeping the air within the building reasonably free of particles of dust and pappus.

The use of a regular cottonseed hopper attached to the clipper mill to remove the pappus was reasonably successful at Saginaw. Elsewhere the cottonseed hopper did not appear to be usable as the materials seemed to "ball up," probably because of the moist conditions. Milnes (29*p*) reports that when the seed is dried thoroughly before cleaning the cottonseed hopper does a good job of removing the pappus.

The greatest difficulty experienced in cleaning seed at Saginaw during the summer of 1943 was the removal of peat or muck particles which had been picked up by the machines. After cleaning with the ordinary fanning mill some of the seed bags contained as much as 50 percent soil, by volume. An attempt was made to remove this by rescreening, but further separation was not possible. There was also some concern as to what mechanical damage the continual recleaning might do to the seed.

Through the cooperation of the Ferrell Company a laboratory model beet seed sorter was made available for testing the removal of soil particles from the seed. A beet seed sorter is essentially a revolving belt built on an incline and mounted on a supporting frame. The uncleaned seed is deposited on the moving belt near the top of the incline. Flat material (kok-saghyz seed) is carried over the top of the incline and the near-spherical particles of muck roll down and off the bottom of the belt. With this equipment approximately 60 percent of the extraneous material was removed from the lots of kok-saghyz seed. With some remodeling and development of a separating technique, practically all foreign material which could not be screened out could be removed with a machine of this type.

A small-scale test was made of the possibility of removing soil particles by throwing the mixed muck and seed against an ordinary 16-mesh wire screen. When the screen was held at the proper angle, the muck went through and the seed fell down the face of the screen.

One of the most satisfactory methods of removing soil particles from the seed was the use of the clipper mill (28*p*) with a burlap screen substituted for the top screen. The uncleaned seed was run through the cottonseed hopper to obtain even distribution on the burlap. As the seed worked down the vibrating screen it was brushed

with a whisk broom to work the soil particles through the burlap. Cleaning with the regular screens gave a purity ranging upward from 58 percent depending upon the amount of soil picked up by the seed-picking machines. By passing the seed over the burlap screen the purity was increased to 93 to 97 percent by weight (fig. 24).

Such seed cleaning as was done was on a very small scale with most of the operations performed by hand. Coster (6*p*) had no difficulty in handling some 1,200 pounds of seed (clean weight) in 1943 under

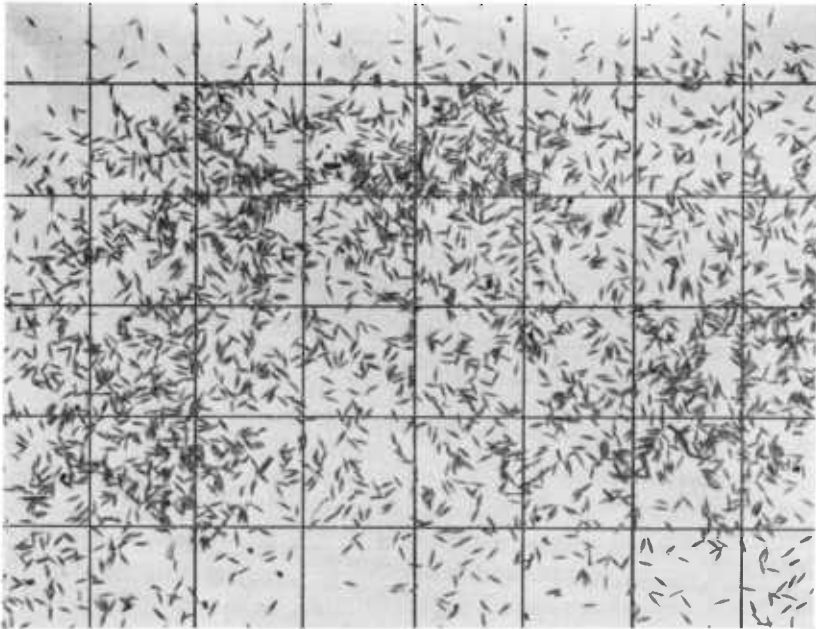


FIGURE 24.—Kok-saghyz seed after screening through burlap. (Forest Service—F-427619.)

Montana conditions, but in the spring of 1944 with more humid conditions he was impressed with the drying space required. Knutsen (24*p*) likewise had no difficulty in handling some 1,000 pounds of seed in Minnesota even though it was necessary to air-dry the seed and to heat the building with two large air circulation furnaces. In any large scale program hand methods would bog down and it would be necessary to mechanize the entire process.

Seed Storage

Little is known about the storage requirements of kok-saghyz seed or how long it will retain viability under different methods of storage. A review of the translations of Russian studies available in 1943 re-

vealed only the single statement that seed should not have a moisture content of more than 12 percent when placed in storage (49). This was interpreted to mean that unless the seed is stored under dry conditions it must be placed in airtight sealed containers after being dried to less than 12-percent moisture content.

Nothing is known about how the Russian seed received in May 1942 was handled before it arrived in this country. It must, however, have been collected in 1941 or earlier and hence would have been at least 2 years old in the spring of 1943. Storage conditions at Beltsville, Md., where it was held from the time of its receipt in 1942 until it was shipped to the field in 1943, were poor and the seed was subject to wide ranges of temperature.

Germination tests made in the spring of 1943 indicated that a considerable portion of the seed received from Russia was of rather low viability and that a larger proportion germinated abnormally. By the summer and fall of 1943 much of the seed not planted in the spring had deteriorated to a point where it was practically worthless.

When Dr. P. S. Makeev, Vice Commissar for Rubber in the U. S. S. R. visited the Minnesota plantings in May 1943, he stated that in Russia no particular attention was paid to problems of seed storage. He indicated that, after cleaning, the seed was simply placed in sacks and suspended from rafters in a granary, a method which may be satisfactory where the seed is gathered one year and sown the next.

Roe (34p) made a preliminary test of storage methods. Some dry seed of Russian origin, supposedly 1941, which had been stored unsealed at room temperature, was dried to 9.3 percent moisture content and placed in a sealed jar at 41° F. in May 1942 for comparison with another lot kept at room temperature. Germination tests were made in April and September 1943 of the lot stored at room temperature and in September of that seed stored in sealed containers.

In July 1942 the original seed lots showed an actual germination of 82 percent with no abnormal seedlings and a potential germination of 92 percent. Potential germination is the actual germination plus the number of sound hard seeds which were ungerminated at the end of the tests.

In April 1943 tests of the seed held unsealed at room temperature showed an actual germination of 45 percent with 19 percent additional abnormal seedlings. There were no sound hard seeds remaining.

By September 1943 viability of this same seed had dropped to 13 percent actual germination plus 26 percent abnormal germination. The September 1943 tests of the sealed seed showed actual germination of 88 percent with one percent abnormal. Cold storage presumably

prepared for germination some of the hard seeds reported in the July 1942 tests.

All of the Russian seed which had a low viability and a relatively high percentage of abnormal germination was destroyed in June 1944.

March 1945 and 1946 tests of 1- and 2-year-old American grown seed stored in sealed containers under cool conditions gave 80 to 90 percent germination.

Roe draws the conclusion that kok-saghyz seed should be dried to about 9 percent moisture content, placed in sealed containers, and kept in storage at a temperature of about 40° F.

ROOT CHARACTERISTICS, ROOT DEVELOPMENT, AND ROOT HARVESTING

Form, Size, and Composition of Roots

Duff, Lehmann, Hamly, and Bannan (*11p*), working under the auspices of the National Research Council of Canada, made a study of the size, form, and composition of individual kok-saghyz roots. Their data from three test plots indicate maximum fresh root weight of between 30.5 and 44.5 grams at the end of one season's growth. Minimum weights range from 2.5 to 4.0 grams and average weights from 14.5 to 16.4 grams. An even greater range of root weights was found in some of the larger plantations in this country.

The indications are that heredity, soil characteristics, and cultivation practices all influence the amount of branching of the roots. It is probable that branched roots are more desirable, because relatively more of such roots are recoverable in the harvesting operation and because there are indications of a concentration of a higher proportion of the rubber within the apical segments of the roots (fig. 25).

In the Canadian samples, dry matter made up between 26.1 and 27.4 percent of the total root weight. There is, of course, some variation in moisture control under different growing conditions and in roots harvested at different times. Second year roots sampled at Plainfield, Wis., on May 3, 1944, had an average moisture content of 86 percent. At Miles City, Mont., moisture content of second-year roots in April 1944 was reported as 81.3 percent and in June, 69 percent. There had been no spring irrigation of this stand but rainfall was considered to be adequate.

Some puzzling questions developed in connection with the calculated root yields based on samplings in the spring of the second year. An effort was made to compare the root weight per acre in early spring with the calculated weight during late October of the previous year but figures permitting accurate comparisons were not obtained.

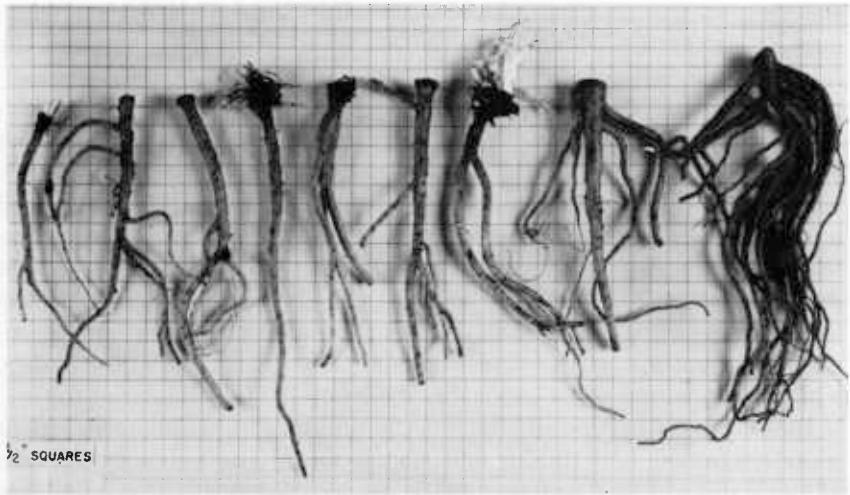


FIGURE 25.—Kok-saghyz roots showing various degrees of branching. (Bureau of Agricultural and Industrial Chemistry.)

There are indications of great fluctuations of root weight between late fall and time of flowering the next spring. Such fluctuations are, of course, the result of utilization of stored materials and the relation of this factor to renewed growth in the spring.

Knutson (25*p*) made a study of average root weights of second-season plants in the Red River Valley of Minnesota through the spring growing season. The first weights were obtained just as the plants were starting growth in the spring of 1944, the second at the time of maximum top growth before flowering, the third, at time of maximum flowering, and the fourth, during period of maximum seed production. The average weights for these 4 periods were 10.94, 7.69, 6.71, and 9.53 grams, respectively.

Russian investigators paid considerable attention to the carbohydrate content of kok-saghyz roots and discovered that fermentable carbohydrates are present in large enough amounts to suggest that their utilization for alcohol productions might be feasible.

Krotkov (21) reports that changes in the water-soluble polysaccharide of kok-saghyz roots, which Russian workers describe as inulin, have received considerable attention. In mature roots he notes that the reducing sugars are low compared with inulin (17, 57). The absolute amount of inulin in 1-year-old roots was found to increase continually throughout the whole growing season, the bulk of it being formed after flowering (17, 45, 46). On the other hand, the highest percentage of inulin, both for 1- and for 2-year-old roots, has been reported at the time of flowering, and it declines somewhat toward

the end of the growing season (23). In *Taraxacum officinale* the highest percentage of inulin has been reported to occur late in the fall (26).

Blokhintseva (7) tried, by microchemical methods, to locate reducing sugars, inulin, and rubber in 1-year-old kok-saghyz plants which were in various stages of development. In leaves, reducing sugars were found only after flower-bud formation. In roots, sugars and inulin were observed for the first time at the time of flower-bud formation. At this stage both sugars and inulin were present inside the root parenchyma cells. Sugars were particularly abundant around the latex tubes, while inulin was spread throughout the whole phloem. At flowering, large amounts of sugars appeared inside the latex tubes, while inulin was seen to be localized in rings around the latex tubes.

Blokhintseva (9) found that by the middle of October kok-saghyz roots contained both inulin and sugars inside the parenchyma cells of both phloem and xylem. After storage for 2 months there was practically complete disappearance of inulin and considerable accumulation of both monosaccharide and disaccharide sugars.

A study made by Lewis and Tatman (37p) indicates a drop in the water-soluble constituents of the roots during the spring growing season. After the height of seed production has passed, the roots again store a large quantity of these substances.

Rubber Formation

Rubber in kok-saghyz is found in latex which is produced and stored in latex tubes. Krotkov (21) in summarizing the Russian findings says that no latex tubes are found in any part of an ungerminated seed (7, 58). Tubes begin to differentiate as soon as water is absorbed during germination, the first of the primary latex tubes appearing in the phloem (4, 58). Secondary latex tubes are differentiated close to the cambium (56).

Latex tubes are produced by fusion of several cells (4, 7, 58), and are living structures containing cytoplasm and nuclei (8, 10).

Latex tubes of the same ring are joined at various levels but there are no connections between tubes of different rings (4, 56, 58) (fig. 26). It has been suggested (44) that all the latex tubes of a kok-saghyz plant form a single continuous system, with the tubes of the leaves joining those of the roots in the crown region.

Krotkov notes that practically all latex tubes of a mature root are formed and attain their maximum diameter before the peak of flowering is reached (46, 56). At flowering the rubber-holding system of a kok-saghyz plant has attained its maximum capacity for the season. On the other hand, the greatest increase in diameter

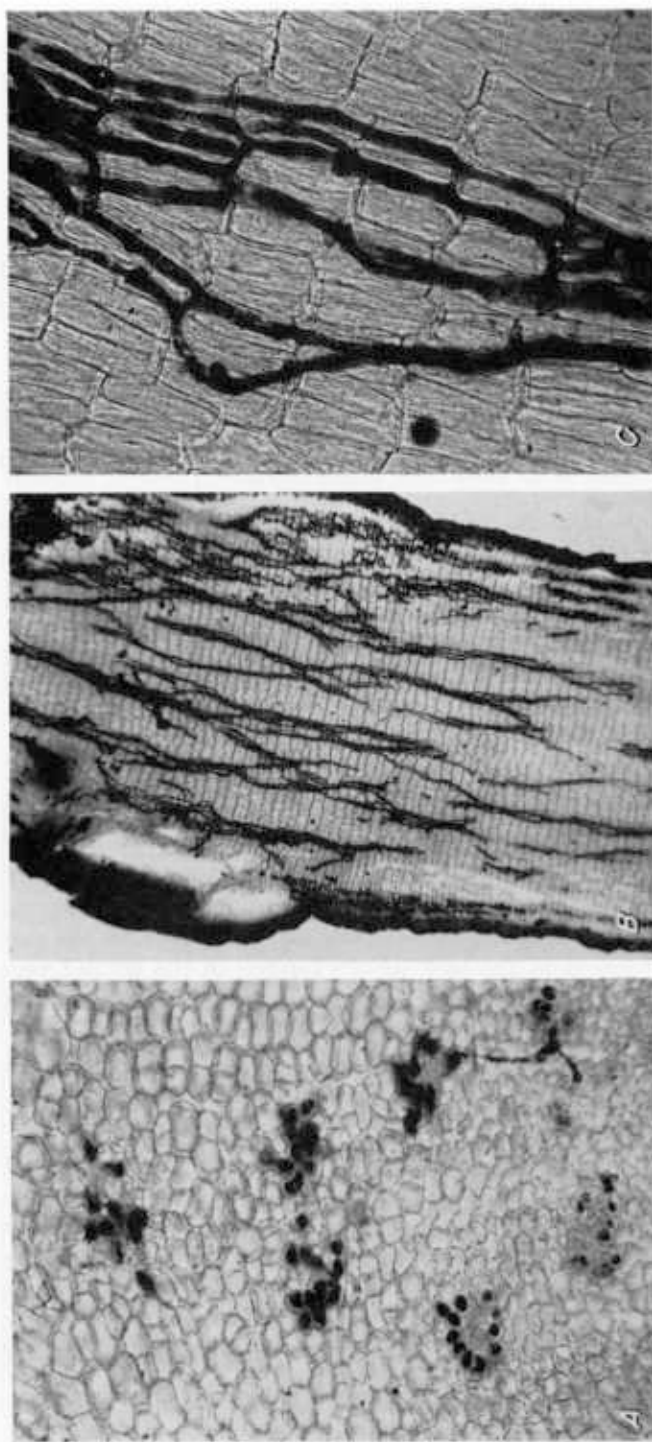


FIGURE 26.—A. Cross section of a kok-saghyz root. The darkly stained material is rubber in the latex vessels, 135 \times . B. Longitudinal section of a kok-saghyz root. Rubber is darkly stained. Approximately 27 \times . C. Enlargement of a section of B showing pattern of latex vessels, 135 \times . (Bureau of Agricultural and Industrial Chemistry.)

of a root as a whole occurs later, after the peak of flowering, and is caused mainly by enlargement of the phloem parenchyma cells. Krotkov points out that as a consequence of this early development of its latex tube system and later growth of the root as a whole there occurs after flowering a decrease in the number of latex tubes per unit area of the root. Since, at the same time, there also is an increase and not a decrease in the percentage of rubber in the whole root, it has been concluded that a considerable simultaneous increase in the concentration of rubber within the latex tubes must take place at this time (46, 56).

Filippov (15) tried to correlate the diameter of a root with the percentage of rubber in it and found the percentage inversely proportional to the diameter. He explained this as being due to the lower number of latex tubes per unit of root area observed in roots of larger size.

A definite gradient in both the number and in the average diameters of latex tubes in a kok-saghyz root has been described (52, 53). The smallest diameter tubes and the smallest number of tubes per area of root section are near the crown.

According to Mynbaev (38), in the first year of growth the percentage of rubber increases until late in the fall, then there is a slight decrease. As a rule the rubber content of roots in the second year of growth is higher than in the first year, while in the third year the percentage goes down.

Mashtakov (31) followed qualitative and quantitative changes both in the rubber and in the resins of 1- and 2-year-old roots in various stages of development and found continuous accumulation of rubber and a decrease in resin content during the whole period of vegetative growth in the first year. The same was true for the rubber and resins produced in the new tissues formed in the second year of growth. On the other hand, in the second year of growth the absolute amount of rubber in the "glove" remained fairly constant until the peak of seed formation had been reached, when it declined as a result of the sloughing-off process. The percentage of rubber in the "glove" had been, however, continuously increasing until the "glove" was sloughed off, an increase attributed to the loss of dry matter in the "glove" itself (30, 31).

The sum of changes in the new tissues produced in the second year of growth, together with changes taking place in the "glove," determines the seasonal variation in the rubber content of the whole kok-saghyz root during the second year of its growth. According to this worker (29, 30, 31), the viscosity, molecular weight, and degree

of polymerization of rubber continuously increase during the normal life of both 1- and 2-year-old roots. He states that depolymerization and quantitative decrease in the amount of rubber takes place only in the dying tissues, or in the "glove." With progress of the season both the absolute and relative amounts of resin decrease.

According to Krotkov, Blokhintseva determined the refractive index of the rubber granules inside kok-saghyz latex tubes and found that in younger plants and in those latex tubes which were closer to the cambium, and consequently younger, the index was higher (6). She suggested that a higher index is due to an admixture of resins, which, in the earlier stages of development, are present in larger amounts.

Krotkov (21) discusses the question of rubber synthesis, noting that as to the place of rubber synthesis in a plant there exist two different opinions. According to one, rubber is produced in the mesophyll of a leaf and is transported as such to other parts. The latex system is, therefore, simply a translocation system. According to the second, rubber is produced not in the mesophyll of a leaf but within the latex tubes, probably from some carbohydrates. The latex system functions, then, both as a means of rubber translocation and as the place of its synthesis.

Obviously, the question of synthesis of rubber in a plant is closely connected with that of its role. It has been suggested that rubber has a protective role, is a reserve substance, or is a waste product. Actually its part in the life of plants is unknown.

Several investigations of general problems relating to latex and rubber formation were undertaken in connection with the kok-saghyz project and have been reported elsewhere.

A few of the more adequate reviews of the subject of latex and rubber formation in plants have been included in the bibliography as being of related interest. The most recent is that by Moyer (37).

The relation of root forms to rubber content and the distribution of rubber within different types of roots was the subject of a preliminary study by Forward and Duff (11*p*). Their results indicate that while there is considerable variation in the amount of rubber in different parts of the root there is, in general, a higher concentration of rubber in the region just below the crown and the region approaching the tip of the root, and less rubber in the middle section of the root (fig. 27).

Experience of several investigators indicates that generally, greater amounts of rubber are found in much branched roots than in taproots of equal weight.

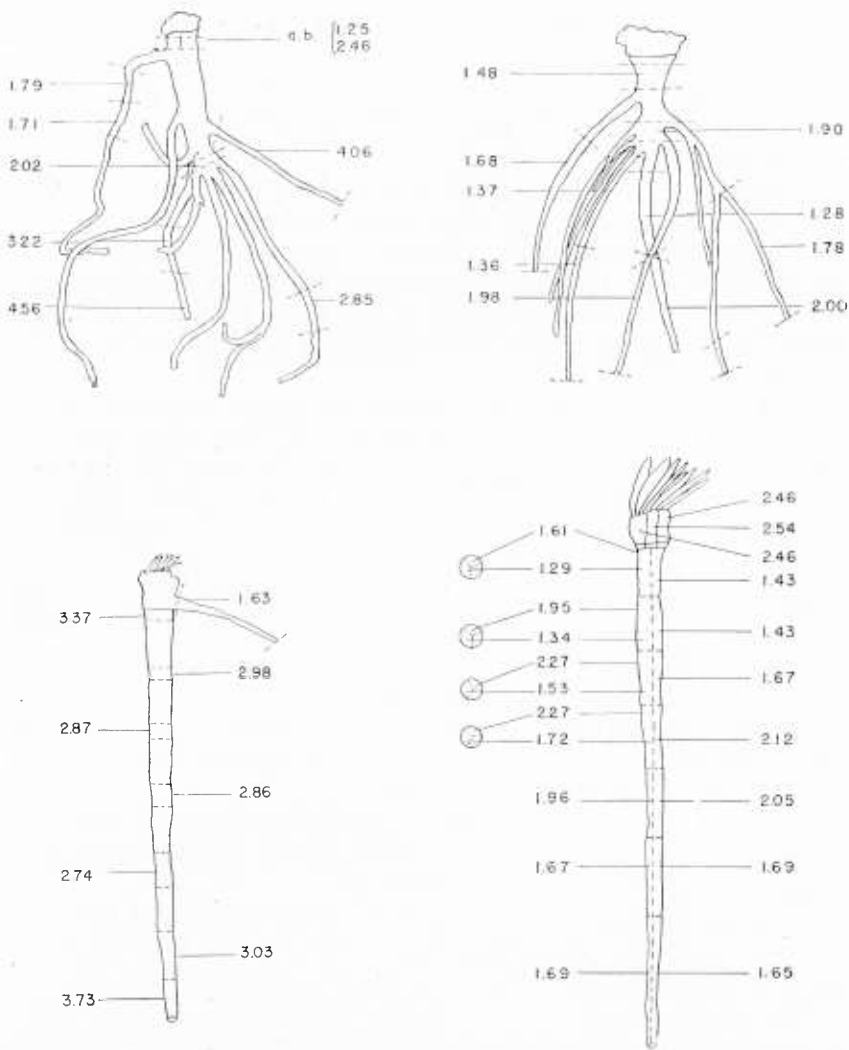


FIGURE 27.—Diagram showing percentage of rubber in various parts of kok-saghyz roots. (From Forward and Duff.)

Time of Harvest

Russian investigators suggest that kok-saghyz roots be harvested either in the fall after a single season's growth or in the spring of the second year. They recommend that harvesting of the first year roots be done as late as possible but early enough to avoid heavy fall rains or frozen ground. According to the articles available, harvesting in the second year should be done just after the peak of the flowering

period, and before the "glove" of accumulated rubber has been sloughed off.

Time of harvest is influenced by many factors including climatic conditions, economic considerations, demands of the extraction plant, availability of labor, and whether or not a seed crop is desired. Consideration must be given to these factors, balanced against the accumulation of rubber in the roots.

All the evidence indicates that accumulation of rubber begins in the young seedling plants but progresses slowly throughout the first months of growth, to be accelerated during the latter part of the first growing season. The accelerated production period seems to coincide with the onset of cooler weather and the renewal of growth after the period of so-called summer dormancy.

The purpose of postponing harvesting in the first season until the latest possible date is to obtain roots of the highest rubber content. There is a suggestion in the data of Knutson and Zehngraff (25*p*, 45*p*, 46*p*) that rubber accumulation continues in the fall after the time when harvesting is feasible.

In the spring, new latex vessels are formed by secondary growth. In these already-established plants, rubber accumulation is much more rapid and takes place much earlier than in first-year plants. At the same time that new rubber is being accumulated, the previous year's latex system, with its accumulation of rubber, is pushed to the periphery of the root where disintegration of the tissues which hold the rubber takes place.

Timing of the harvest operation in the second year should be such as to take maximum advantage of new rubber formation and still recover the previous year's accumulation of rubber. Too early harvesting will not recover a high enough proportion of this newly formed rubber. Harvesting too late will result in the loss of the previous year's accumulation. When disintegration of the old tissues is complete the rubber in the "glove" is separated from the root and is not recoverable. Whether this rubber actually disintegrates has not been demonstrated but it is not recoverable by mechanical harvesting methods.

All the experience in this country supports the Russian contention that the optimum time for second year harvesting operations, is the period immediately following the first peak of flowering. However, further study of this problem is necessary, for it is now recognized that strains of kok-saghyz differ considerably in their flowering habits.

While it is generally thought that harvesting should be done either at the end of the first season or in the spring of the second season, there is not yet sufficient available information to suggest definitely that still later harvest might not be economical.

In the fall of 1943, harvesting was delayed as long as was thought, on the basis of local experience, to be safe. Approximately 190 tons of roots, green weight, were harvested before cold weather and rain brought operations to a close. Roots were harvested in the Red River Valley of Minnesota between October 23 and November 10; at Missoula, Mont., between October 19 and November 5; and at Saginaw, Mich., between October 12 and November 12.

In the spring of 1944, roots were harvested in the Red River Valley between April 13 and 20 and again between May 20 and 26, and at Missoula, Mont., between April 12 and 20 and again between June 15 and 22.

Roots from plantings made in the fall of 1943 at Belle Glade, Fla., were harvested in April 1944.

Method of Harvest

Milner (36) explains that the harvesting of kok-saghyz roots in Russia is done with sugar-beet lifting equipment and points out that such equipment is adapted to use on kok-saghyz but does not say what modifications are made. Apparently few efforts were made by the Russians to mechanize root-harvest operations, partly because of a general lack of mechanized equipment and partly because an abundance of labor existed. Hand digging and lifting and simple plowing-out of roots were used in many of their plantings.

It was obvious from the beginning that in this country mechanization of the root-harvesting operation would be necessary.

In harvesting kok-saghyz roots the problem is to recover the maximum amount of root with the minimum of breakage or bruising. The branched roots of kok-saghyz are much more difficult to handle than the compact modified root structures of most cultivated root crops. The distribution of rubber in kok-saghyz roots is such as to demand recovery of a major part of the lower sections of the root. Such recovery has to be accomplished without excessive damage to the roots because wherever a root is broken or bruised, latex is exuded. While most of the exuded latex may stick to the root in the form of a scab, it picks up particles of soil and other debris which complicate the purification of the rubber in the extraction processes.

In the fall of 1942, attempts were made to use standard potato diggers for harvesting the kok-saghyz roots on the light sandy soils in the Forest Service nurseries of the Lake States. It was apparent from the preliminary trials that none of the models available would work satisfactorily without extensive modification. Inasmuch as it was late in the season and roots were in demand for testing, they were simply plowed out and picked up by hand. Harvesting in Montana

was done with a sugar-beet lifter which, according to Coster (5*p*), did a reasonably good job of lifting the roots from the first 9 inches of soil.

In 1943, when a large acreage was planned and attempts were made to introduce standardized spacings, planting densities, and cultural methods, the need for mechanical harvesting became acute. The 1942 experience had suggested the possibility of effectively modifying potato diggers and sugar-beet lifters and had emphasized the various steps in the harvesting operation.

In hand harvesting in Russia the tops are cut from the plants individually, an operation which requires much hand labor. In the 1942 harvest in this country topping seemed to be the largest user of hand labor and it was soon found that this operation could be speeded up with an ordinary garden hoe. Later a scuffle hoe was modified to speed up this hand operation.

Believing that mechanized topping was relatively simple, 1943 efforts were confined to the development of a digging and lifting machine. Starting with a power-driven potato digger, Ramp (32*p*, 33*p*) developed a machine pulled by a tractor and designed to handle two rows spaced 16 inches apart. A satisfactory trial was conducted in the light sandy soil at the Cass Lake Nursery, Minn. (fig. 28). A cart with a $\frac{1}{2}$ -inch mesh hardware cloth floor was pulled behind the digger to catch the roots. In the absence of a satisfactory mechanical topper, a scuffle hoe was used and since the Eastern Regional Research



FIGURE 28.—Modified potato digger harvesting kok-saghyz roots on sandy soil. (Forest Service—F-427696.)

Laboratory requested that shipments of roots be kept free of top material, tops were raked off the field before the roots were harvested.

Based on preliminary trials early in 1943 at Cass Lake, modifications of this power digger were made to adapt it to the heavier soils on which most of the kok-saghyz was being grown. The digging nose was reduced to handle only one row at a time and was built in the form of a trough.

This modified machine was tried out in October 1943 on the heavy wet silt loam soils at Crookston, Minn., but did not work effectively. It was then moved to the drier, somewhat lighter, soils at Moorhead where it worked more effectively although difficulty was experienced when it was set to the full digging depth. There was also some difficulty in keeping the nose centered on the row.

In operation this modified power-driven potato digger was set to cut the kok-saghyz roots and elevate to the conveyor shaker screen as much earth as could be moved with the available tractor power (fig. 29). The cross section of the earth moved was about 8 or 9 inches wide by 9 or 10 inches deep. The soil and roots were conveyed over a shaker screen which was designed to separate the roots and deliver them to the side of the harvested row.

Topping has as its purpose the removal of the leafy portions of the plant to prevent their inclusion with the harvested roots. There



FIGURE 29.—Side view of tractor-drawn, power-driven modified potato digger showing digging nose and conveyor chain. (Forest Service—F-427693.)

are several objections to inclusion of top portions of the plant. The leaves and flower stalks contain relatively high concentrations of pectic substances the presence of which complicates rubber extraction. They may also contain considerable quantities of very low quality rubber, an objectionable contaminant.

By the time harvesting operations were ready to start in October 1943, Ramp had built two types of topping machines (32*p*). One was a motor-propelled rotary mower. Topping at or just under the surface of the ground was desirable, but it was not possible to cut the tops at the desired level, about $\frac{1}{2}$ inch above the crown, with this machine. The other topper was of a sliding-knife type and while it was possible to top the plants at the proper level with this machine, the operation was slow and it was difficult to keep the blade sharp.

In the meantime, Knutson (24*p*) had developed the use of cultivator weeding-knives for topping. He found that the tractor operator could raise or lower the weeding knife and do a satisfactory job with this device. He then mounted a "shoe" to run on top of the ground to keep the knife from going too deep and a compression spring to hold the knife down, thus increasing the speed and efficiency of the job. He later mounted four sets of knives on a cultivator bar on the tractor permitting the topping of four rows at one time (fig. 30).



FIGURE 30.—Cultivator blades adapted for topping kok-saghyz. (Forest Service—F-427687.)

This arrangement did not work so well on uneven ground since one or more sets of knives either floated above ground or cut too deeply. This topping device left the tops in place, however, and thus facilitated location of the row for the root-harvesting operation.

Because of the failure of the modified potato digger to work satisfactorily in heavy soils, Knutson, at Moorhead, constructed a modified sugar-beet lifter which was run under the rows to loosen the soil and raise the roots. The roots were then gathered by hand. This operation was slow and expensive but it recovered over 90 percent of the roots as compared with 50 to 60 percent recovery with the potato digger. Many of the roots were cut off at less than 8 inches below the surface, thus resulting in a heavy loss of rubber.

At Plainfield, Wis., on peat, a potato digger mounted on a three-wheeled rubber-tired farm-type tractor was equipped with a special digging nose similar to the one used at Moorhead. It did a reasonably good job and was used for lifting approximately 13 acres.

At Saginaw, Mich., it was necessary to start the harvesting operations without the especially modified potato digger. After trying out several light potato diggers, the roots were plowed out and picked up by hand.

On all fields it was possible to dig only one row at a time with the modified potato digger, and the roots from that row had to be picked up by hand before the adjoining row could be harvested. In order to obviate the delay made necessary by hand picking the roots, fields were laid out in "lands" so that the tractor and digger could make several round trips before having to start back on the row adjacent to the one first dug.

During the winter of 1943-44 an attempt was made to develop a digger without the undesirable characteristics found in the tractor-drawn potato digger and the modified sugar-beet lifter. To this end Ramp constructed a digger mounted below the frame of a farm-type tractor (33*p*) (figs. 31 and 32).

Following the operation of the tractor-drawn potato digger, Green (15*p*) found that 11.4 percent of the roots lifted were buried with soil and therefore not readily recovered.

To determine the proportion of the individual roots recovered, Green compared recovery with the potato digger with hand digging to a depth of 18 inches. His data show that the mechanically recovered portion of the roots amounted to 76.5 percent of the total amount of root to the 18-inch level. To relate these figures to rubber recovery, assays were made. Based on dry weight, the top parts showed 4.15 percent rubber, while the 9- to 18-inch parts not recovered with this equipment showed 5.62 percent rubber. In terms of rubber yield, the roots harvested contained 73 percent of the total available



FIGURE 31.—Front view of kok-saghyz digger mounted under the frame of a farm-type tractor. (Forest Service—F-429928.)



FIGURE 32.—Rear view of digger shown in figure 31. (Forest Service—F-429926.)

rubber, the roots dug but lost in the harvesting operation, 11 percent, and the 9- to 18-inch portion of the root, which could not be dug with this equipment and perhaps cannot be recovered at all, contained 16 percent of the total rubber.

On most soils it would be undesirable to attempt to recover roots below the 8- to 10-inch level even though equipment and power were available to do so. Digging below this level would usually turn up such a quantity of subsoil as to seriously affect the productive capacity of the land.

Roots were picked up in hampers or boxes and dumped on screen trays to facilitate hauling to a central location. This method was used on all fields except at Saginaw, Mich., where the roots were hauled directly from the field to the root-washing machine. Thereafter, they were stored in shallow pits and temporarily covered with sugar-beet tops until shipped. The weather was cool and there was no loss in the stored roots.

While a thoroughly satisfactory solution of the root harvesting problem was not worked out during 1943 or 1944 enough progress was made to indicate clearly that no serious difficulties are to be anticipated in developing adequate methods for digging and lifting the roots.

ROOT HANDLING

Washing and Drying

It was found that under certain conditions washing of the roots was necessary. A root washer modeled after standard vegetable washers was developed at Saginaw, Mich. (28*p*). This washer consisted of a section of corrugated iron culvert pipe mounted on rollers and set at a slight slope in a frame. Holes one-half inch in diameter were drilled in every other ridge of the pipe to allow drainage of water and soil. A spray pipe was inserted a short way into the cylinder near the upper end. Roots placed in the upper end of the cylinder gradually worked down the slope as the cylinder was rotated. By the time the roots reached the lower end they were clean. This machine worked very satisfactorily.

Knutson (24*p*) found that chunks of loam and silt loam adhering to the roots interfered considerably with root drying and he recommended that all roots be washed immediately after lifting while the adhering soil is quite loose. Handling unwashed dried roots is a dusty job, particularly roots grown on peat soil. When the Plainfield, Wis., roots were being packaged for shipment the drying room was filled with fine floating particles of peat and respirators were required.

Whether washing of the roots would be a requirement of any kok-saghyz production program has not yet been determined although the procedure is recommended by Eskew (14*p*).

The handling of the roots after harvest will depend upon whether they are to be milled immediately or stored for future milling in a year-round operation, and the nature of the shipping problem.

Where roots are not to be milled immediately, the Russians recommend drying the roots at temperatures of less than 140° F. to a moisture content of approximately 30 percent and caution against drying them in direct sunlight.

Roots were dug at Cass Lake, Minn., in early May 1943 for an experimental drying test. McQueen (27*p*) reports that the roots dried satisfactorily in the open air in 10 to 12 days. Satisfactory drying was also obtained in a building which had good air circulation even though there was some precipitation on several days during the drying period. Later, time tests were also made of drying roots in a thermostatically controlled drying kiln. When the kiln was only partially filled, it required 22 hours at a temperature of 130° F. to dry the roots. When the kiln was filled to capacity, it required more than 4 days to complete the drying job.

McQueen's studies show that the weight of a cubic foot of uncompressed fresh green roots of the second-year crop at Cass Lake averaged 16 pounds. In the process of drying the roots lost an average of 26 percent of their volume and their weight was reduced to an average of 6.1 pounds per cubic foot. A cubic foot of dry roots* compressed slightly averaged 8.3 pounds.

One Russian investigator, Tikhov (61), indicates considerable difficulty in air drying roots in the fall because of cool or rainy periods. The Cultivation of Kok-saghyz (49) suggests drying be done under a roof, in layers 10 centimeters thick (approximately 2½ inches) and recommends that the drying roots be stirred often to prevent heating.

In the fall of 1943 plans were made to partially dry the roots in the open air and to complete the drying under shelter, using heat if necessary.

In Crookston, Minn., racks of 4-foot shelves floored with one-half-inch mesh hardware cloth were constructed within a building. Roots were piled about 6 inches deep on the shelves, which were stacked 6 shelves high. Racks were built 3 to 4 feet apart to facilitate turning the roots. Approximately 45 tons of green roots were dried in this manner. The operation required about 5,000 square feet of floor space.

During the early part of the drying season when only a relatively few roots were in the building drying progressed satisfactorily. When the building was filled with fresh green roots the atmosphere became saturated with moisture. This increase in relative moisture content of the air was also traceable in part to changes in weather conditions. When artificial heat was provided conditions favored the growth of

molds and rots. Fans were used to circulate and exhaust the moisture-laden air.

In Moorhead, Minn., approximately 15½ tons of roots were dried in a seed-corn drier. This seed-corn drier was a two-story building with a large hot air furnace which circulated heat upward through numerous openings in the upper floor. This system of drying worked satisfactorily with corn but the kok-saghyz roots fitted together more closely and there were not sufficient openings for the hot air to pass through the masses of roots. The roots were stacked 18 inches deep and were turned over with forks every 24 hours. They remained in the drier for 6 days and 5 hours, a length of time involving excessive costs.

At Saginaw, Mich., drying was done in a building equipped with a hot air heater. Partitions were removed so that a drying rack approximately 30 feet long was centered over the furnace. The roots immediately above the furnace dried rapidly but air circulation was not sufficient to carry the warm dry air to the two ends of the rack. However, after electric fans were installed to distribute the hot air, drying was quite uniform.

While it is probable that harvesting and processing schedules could be arranged so that drying of the whole crop would not be necessary further attention to this phase of the work is essential; for it is likely that under any system some of the roots will have to be dried prior to later milling.

Storage

There are two different storage problems with kok-saghyz roots: short-term storage to accumulate fresh roots for immediate milling, and storage of roots to provide for year-round operation of extraction plants.

Ignat'ev, Uzina, and Erofeev (16) and Neuman and Dobrovol'skaia (42) have reported on extensive tests of different methods of storage and their effects upon roots and rubber and carbohydrate content. Fresh roots were stored outdoors in shallow pits and covered with burlap, straw, or other material. Roots were also stored in bags and protected against rain but not against temperature changes. Laboratory tests were made of the effects of various conditions upon small lots of roots.

Their general conclusions were that undried roots can be stored for a period of about 6 months following their harvest in October. Roots will withstand temperatures down to -12° F. without damage. Pit storage is satisfactory if the pits remain dry. Neuman and Dobrovol'skaia suggest that there is actually an accumulation of rubber during such storage but point out that there is a sharp decline in the carbohydrates during this period.

It was planned that in 1943 the pilot extraction mill located at the Eastern Regional Research Laboratory, Bureau of Agricultural and Industrial Chemistry, Philadelphia, Pa., would begin operations at the time of fall harvest. However, difficulties in obtaining materials delayed completion of the mill until early spring 1944.

This fact made it necessary to study both the methods of storing fresh roots and methods for drying roots to condition them for longer storage. One lot of roots was shipped to the pilot plant without drying. After a considerable period of exposure without any attempt to protect the roots from changes in temperature and moisture and before they could be milled, they rotted badly. Handling was difficult and most unpleasant.

No experiments in holding freshly harvested roots under controlled temperature and moisture conditions were carried out.

Estimates of the magnitude of the storage operation are included in the report of the Eastern Regional Research Laboratory (14p).

Shipping

A cubic foot of fresh roots weighs from 16 to 20 pounds with an average of about 18 pounds. A ton of fresh roots would occupy about 110 cubic feet of space. In drying, the volume shrinks about one third and the space requirement is reduced to about 70 cubic feet. A cubic foot of dried roots averages about 8 pounds in weight.

The average 40-foot box car holds about 8 tons of loose dried roots but minimum carload freight rates for agricultural commodities require payments on from 10 to 15 tons. Therefore, some baling process to reduce the space required per ton and to increase the weight per cubic foot was thought desirable. Baling should be done in such a way as to hold breakage of the brittle dried roots to a minimum.

In baling experiments two types of bales were built up, one using hardware cloth as the outside container, the other, burlap. Six cubic feet of loose roots were compressed into 4.12 cubic feet in the wire-cloth bale. Ten cubic feet of loose roots were compressed to 4.68 cubic feet in the bale having burlap as the cover. After 10 days, sample bales were opened and inspected. Roots in the wire-cloth bale were in good condition with but little breakage. Roots in the burlap bale showed but little breakage but did show some mold. When shipped to the pilot plant, a wire-cloth bale arrived in perfect condition while burlap bale became loose.

At Saginaw, Mich., a test was made using the Economy Baler. As the roots came from the drier they were rather brittle but baling was accomplished with a minimum of breakage. However, after the bales had stood several days the tie-wires became loose and it was apparent that such bales would not ship without damage except possibly in car-

load lots where handling would be much less. The weight of the bales had increased about 4 percent and on opening them it was found that the roots had lost their brittleness, apparently having resorbed moisture from the atmosphere. These roots were again baled tightly and while the wires loosened a little during storage, they remained tight enough for handling.

Knutson (24*p*) reports an interesting study of volume and weight changes in roots in the process of coming to a moisture equilibrium after drying. Ten samples of dried roots of 1 cubic foot each were weighed and moisture content determined. After exposure to atmospheric moisture conditions for 18 days the average weight increased 3.7 percent while the volume decreased 35 percent.

Knutson had noticed an unequal response of the roots in reaching moisture equilibrium and felt that the initial moisture content of the dried roots had something to do with it. He repeated the experiment using only the drier roots. His conclusion was that roots with an original moisture content of 15 percent or less resorbed moisture more slowly than roots which originally had a higher moisture content. In the latter study, two of the samples actually lost weight after exposure to atmospheric conditions, but all of the samples shrank in packaged volume.

Inasmuch as there were insufficient dried roots to form a carload, either loose or baled, at Plainfield, Wis., and since burlap was extremely difficult to purchase, the dried roots at this point were simply sacked for shipment, using second-hand burlap sacks.

EXTRACTION METHODS

Rubber

Kogan (18) gives a review of the Russian work up to 1939 on the extraction of rubber from kok-saghyz to which the Russians had paid considerable attention. They had also developed suitable equipment.

Consideration was given to the suggestion of Russian investigators that sugar-beet milling equipment be used in the off-season for extracting rubber from kok-saghyz. However, numerous factors dictated design and construction of a new mill of a different type.

When studies were started at the Eastern Regional Research Laboratory (14*p*) on the development of a process for recovering rubber, only fragmentary information was available on the process used in Russia. It was reported that the Russians had done some work on extracting latex from the roots, but their yields were quite low. A few preliminary experiments showed a great many difficulties inherent in such a process and furthermore a method which could be used on dry as well as fresh roots was desirable.

The Russians were supposed also to have used a process based upon chopping the dried roots and boiling them in dilute caustic to destroy plant tissues. The fine particles of rubber so released were then separated by repeated centrifugal and gravity sedimentations. Since treatment with caustic tends to impair the quality of rubber and since the centrifugal sedimentation equipment is elaborate and expensive, a different approach was made to the problem.

It was known that kok-saghyz roots contain carbohydrates, a possible source of valuable byproducts. Therefore, the first step was to leach the roots in hot water to remove the carbohydrates. When this was done it was found that the tissues were softened and the latex had coagulated in fine filaments. It appeared that the proper manipulation of the softened roots in water might loosen and flush away the tissues, leaving the rubber.

Pebble milling the leached roots in water, as is done with guayule, was therefore tried, but it was found that excessive millings were required to obtain complete isolation of the rubber from the plant tissues so that they could be separated by flotation. Furthermore, the consistency of the kok-saghyz slurry in the pebble mill was such that the total solids in the system had to be kept quite low thus further reducing the capacity of the pebble mills. These difficulties were overcome by a process worked out by R. K. Eskew and P. W. Edwards of the Eastern Regional Research Laboratory and covered by United States Patent No. 2,393,035.

This process consists of pebble milling the leached roots for about 20 minutes in water using a ratio of 20 parts of water to 1 of solids. This operation rolls together the fine filaments of rubber and loosens most of the soft plant tissue. The slurry from this milling, when diluted with 5 times its weight of water, is then passed over a vibrating screen thus eliminating, through the screen, 60–65 percent of the root solids other than rubber. The material passing over the screen consists almost entirely of rubber contaminated with some root skins and other tissue fragments. A secondary pebble milling for 22 minutes using about 22 parts of water to 1 of solids further eliminates the nonrubber constituents so that the conventional continuous flotation process recovers the rubber by floating it away from the plant debris. This rubber is then washed on a vibrating screen and again floated to eliminate traces of entrapped plant debris. After dewatering in a centrifuge, antioxidant is added to the rubber in a mixer and it can then be dried in a continuous through-circulation, multiple-belt drier.

The process thus worked out recovers well over 90 percent of the total rubber in the roots and, according to Russian representatives with whom the process was discussed and who saw a moving picture of the pilot-plant operations, the method is much simpler than any they had developed (figs. 33 and 34).

FLOW DIAGRAM FOR KOK-SAGHYZ FACTORY TEN LONG TONS OF RUBBER PER DAY

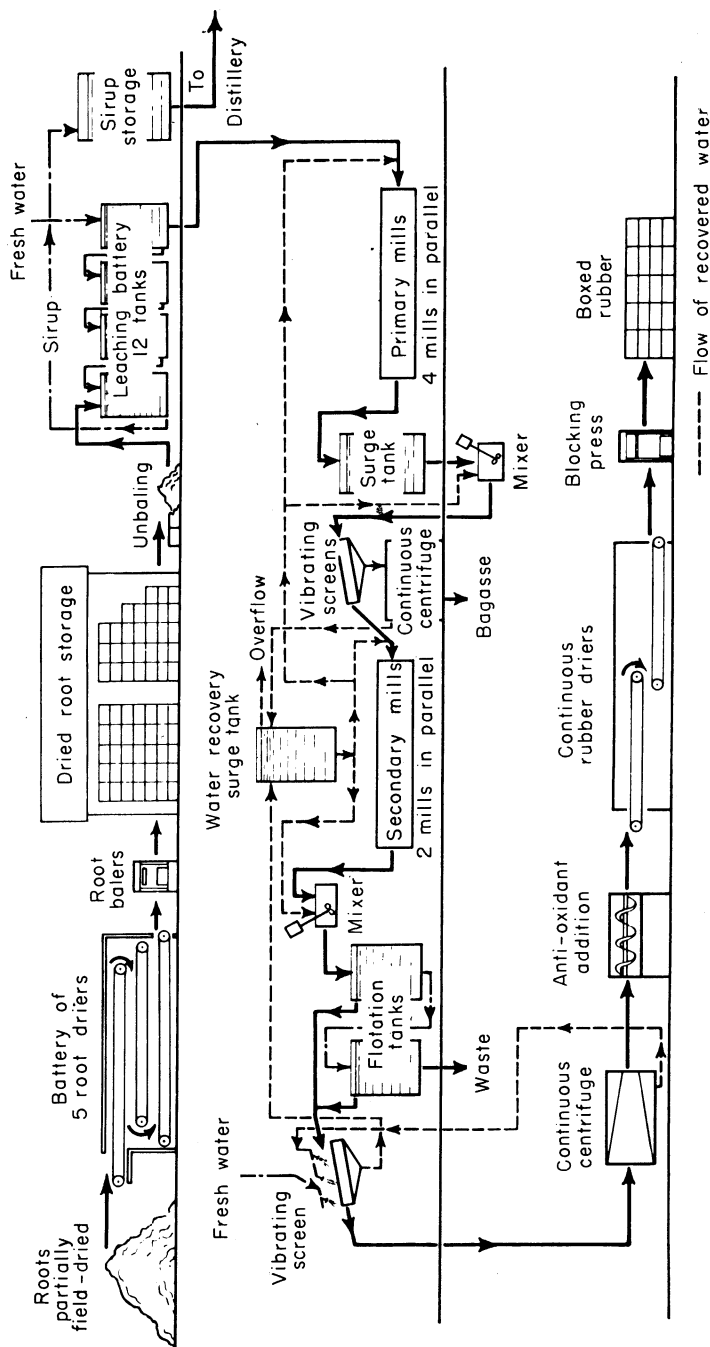


FIGURE 33.—Diagram showing processing steps in pilot-mill extraction of kok-saghyz roots. (Bureau of Agricultural and Industrial Chemistry.)



FIGURE 34.—Blocks of kok-saghyz rubber at the Eastern Regional Research Laboratory, Philadelphia, Pa. Viewing rubber are, left to right, Hon. W. R. Poage, Hon. Victor Wickersham, Hon. John Phillips, and Hon. Anton Johnson of the U. S. House of Representatives. (Bureau of Agricultural and Industrial Chemistry.)

Byproducts

While primary emphasis was on development of methods of rubber recovery, it was found that inulin and other carbohydrates were leached out of the roots in the first leaching treatment. These substances, if obtainable in sufficient concentration, are possible sources of ethyl alcohol and other fermentation products. Exploratory experiments have shown that *Lactobacillus delbrückii* produces lactic acid and *Saccharomyces cerevisiae* produces ethyl alcohol, both in fair yield, from kok-saghyz leach-liquors.

Eskew (14*p*) indicates that fall dug roots contain 40 to 50 percent carbohydrates by weight while roots harvested after the plants start growing in the spring may contain as little as 10 percent.

The plant tissues which are recovered from processing waters in order to permit re-use of the water contain proteins and fats and may have byproduct value.

KOK-SAGHYZ RUBBER

Yield

Russian workers have given few figures on yield of kok-saghyz roots from which the rubber is extracted, and it was realized from the beginning that yields would be related to the type of seed used and numerous local factors.

Altukhov (3) reports 100 to 112 centners per hectare while in another paper (2) he reports only 50 to 60 centners per hectare. Elkin (14) indicates the average yield is 35 centners but that this may be increased to 100 by good practices. Lysenko (27) states that some collective farms which were successful in securing good stands produced as much as 50 to 70 centners per hectare. Milner (36) records that one farmer harvested 36 centners per hectare but he also speaks of another farm on which 35 centners were harvested one year and only 23 the following year. One report (49) gives the yield of first year roots as 30 to 50 centners per hectare, while Takushin (60) reports 100 to 118 centners. Another publication (62) indicates that one farm produced only 19 centners of second-year roots. It also gives various other figures ranging from 23.7 to 46 centners per hectare and lists two high yields of 75 centners. Zasiadnikov (66) reports 23 to 45 centners. It would thus appear that the average Russian yields range from 35 to 45 centners per hectare.

A centner is equivalent to approximately 110 pounds. However, as it is understood that the centners referred to in the cited Russian papers on kok-saghyz are actually double centners, the average weight of roots produced per hectare in Russia would be from 7,700 pounds to 9,900 pounds. This would be approximately 3,100 pounds to 4,000 pounds per acre.

In 1942, 5,260 pounds of roots, fresh weight, were dug at Cass Lake, Minn., and 8,600 pounds at Manistique, Mich. The yield of roots averaged 1,846 pounds per acre at Cass Lake and 2,688 pounds at Manistique. The Cass Lake lot averaged 4.78 percent rubber based on the dry weight of the roots while that from Manistique averaged 4.45 percent.

In late October 1942, 5 acres dug at Missoula yielded 2,950 pounds, fresh weight, or an average of 590 pounds per acre. Analysis showed

4.43 percent rubber based on the dry weight of the roots. The stand was very poor. Had there been as many as 4 plants per linear foot the yield probably would have exceeded 4,000 pounds per acre.

The best production of roots in 1942 was a calculated yield of 8,328 pounds, fresh weight, per acre from a small test plot at Geneva, N. Y. A small plot at St. Paul, Minn., gave an indicated yield of 7,934 pounds per acre, fresh weight.

In 1944 Zehngraff and Aamodt (46*p*) calculated rubber yields from the roots of second-year stands in Minnesota as from 64 to 97 pounds per acre on May 27 and from 74 to 108 pounds per acre on June 12.

Table 9 shows the 1943 calculated root yields. Most of the fields had stand densities much less than considered adequate. Theoretical yields per acre, calculated from sample yields of the best areas in the Lamb field at Moorhead and the Ross field at Crookston, were 8,500 pounds and 8,800 pounds respectively. One sample 5-foot plot in the Bekkerus B-2 field grown from presprouted seed with 51.6 plants per linear foot gave a calculated yield of 9,051 pounds per acre.

Root samples were dug on March 16, 1944, at Belle Glade, Fla. These samples indicated relatively light yields per acre for both the November and the January sowings, but samples dug on April 21 indicated a maximum yield of 6,444 pounds per acre for the November sowing and almost as much, 6,408 pounds, for the January sowing. Erambert (13*p*) conducted a rather careful thinning test with results similar to those reported for the Lake States areas. A calculated production of 3,456 pounds where the stand was thinned to 4 plants per linear foot increased to 4,176 pounds with 8 plants per linear foot and 5,616 pounds where there were 20 per linear foot. Erambert reports that the heaviest weight of roots was secured with 115 plants per linear foot.

Rubber analyses of roots from the November 1943 seedlings harvested in April 1944 ran from 4.05 to 5.11 percent based on dry weight. The lower assay of the roots from the January 1944 seeding, 3.14 to 3.94 percent suggests that the plants had not reached their maximum rubber content. These plants, less than 4 months old, had a slightly higher rubber content than northern grown plants of about the same age.

Sampling of several fields in the Red River Valley of Minnesota in late April 1944 showed in general a slightly increased fresh weight of roots per acre over the fall 1943 weight wherever the average density in the spring was close to the average of the previous fall. In these samples the average rubber content based on dry weight of roots was slightly less in the spring than in the fall.

At San Clemente, Calif. (12*p*), samples were taken on June 6, 1944, for calculation of root yields. The calculated yield of the October

TABLE 9.—*Calculated kok-saghyz root yields*

Location—State, place, field	Soil type	Area brought through	Date sown	Date sampled	Maximum yield		Average yield		Rubber content
					Plants per linear foot	Weight per acre	Plants per linear foot	Weight per acre	
Minnesota:									
Moorhead:									
Bekkerus B-1	Bearden loam	5.77	Apr. 22, 1943	Oct. 22, 1943	13.4	3,230	5.9	2,208	4.83
O. Skolness	do	30.91	Apr. 23-28, 1943	Oct. 23, 1943	19.6	5,157	5.6	2,798	5.79
Grover	do	19.09	Apr. 28-May 1, 1943	do	22.2	6,106	6.7	3,420	4.37
Lamb	do	23.72	May 3-4, 1943	do	26.0	8,522	14.9	5,974	4.96
A. Skolness B-1	do	24.63	May 7-11, 1943	do	16.2	4,695	8.1	2,798	3.83
A. Skolness B-2	do	23.07	do	do	21.6	4,587	8.2	1,579	4.64
Bekkerus B-2	do	4.75	May 30, 1943	Oct. 22, 1943	21.0	5,170	7.9	2,372	4.64
Crookston:									
Wagner B-1	Bearden silt loam	3.53	Apr. 24-25, 1943	Oct. 28, 1943	13.6	7,165	4.6	3,381	5.71
A. Thureen B-1	do	19.46	May 13-14, 1943	Oct. 29, 1943	12.8	4,125	4.3	2,995	5.83
Ross	do	28.31	May 17-19, 1943	Oct. 27, 1943	15.0	8,820	4.3	3,600	5.30
Woodstrom	do	36.96	May 21-22, 1943	Oct. 28, 1943	11.2	5,537	7.0	3,266	4.48
Wagner B-2	do	15.78	June 11-12, 1943	do	14.4	5,889	4.4	2,723	4.75
T. Thureen B-1	do	16.00	June 12, 1943	Oct. 29, 1943	13.4	5,089	9.0	4,367	4.96
T. Thureen B-2	do	10.28	June 18, 1943	do	5.4	3,216	2.9	2,190	4.22
A. Thureen B-2	do	5.60	June 29, 1943	do	2.8	1,276	1.4	774	2.98
Woodstrom	do	(3)	July 1, 1943	Oct. 28, 1943	5.8	2,280	3.1	1,274	3.76
Aitkin:	Peat	4.79	June 23-July 9, 1943	Oct. 30, 1943	25.0	2,114	14.0	1,130	2.37
State	do	0	June 24-25, 1943	do	43.2	2,383	14.3	1,184	2.85
Gleason	do	30.23	July 7-11, 1943	do	19.8	2,337	---	---	1.7
Stewart:	Webster silty clay loam	0	Apr. 28-29, 1943	Nov. 2, 1943	14.2	1,547	---	---	4.121
Original	do	0	June 19, 1943	do	---	3,025	Fair	---	3.57
Cass Lake (second year)	Loamy sand	28.00	1942	Sept. 13-30, 1943	---	---	---	---	5.02
Michigan:	do	10.4	1942	Sept. 25, 1943	---	4,000	Poor	---	5.83
Manistique (second year)	do	52.0	June 4-30, 1943	Oct. 31, 1943	---	3,173	6.0	2,572	6.7
Saginaw:	Carlisle muck	18.0	June 24-26, 1943	do	---	6,498	Poor	197	4.2
Alicia	Loamy fine sand	39.0	May 13-18, 1943	Oct. 22-Nov. 6, 1943	11.3	---	---	2,740	4.68
Eisenhauer	Rifle peat	---	---	---	---	---	---	---	---
Wisconsin:	---	---	---	---	---	---	---	---	---
Plainsfield	---	---	---	---	---	---	---	---	---
Montana:	---	---	---	---	---	---	---	---	---
Missoula:	---	---	---	---	---	---	---	---	---
Russian seed	Silt loam	---	June 12, 1942	Oct. 15-19, 1943	4.0	3,532	---	2,291	6.0
Russian seed	do	---	May 19, 1943	do	3.3	1,580	2.4	1,540	4.2
Local seed	do	---	May 9, 1943	do	13.7	3,803	10.5	2,810	4.2
Oregon:	---	---	---	---	---	---	---	---	---
Klamath Falls	Fine sandy loam	6.56	May 26-29, 1943	Oct. 12, 1943	---	---	---	1,269	3.65
Peat	do	23.0	May 15-17, 1943	Oct. 16, 1943	---	---	---	1,320	5.53
New York:	Loamy fine sand	4.0	May 20, 1943	Oct. 13-20, 1943	---	---	---	1,155	4.89
Seneca Falls	do	7.3	June 12, 1943	Oct. 4-8, 1943	---	---	---	1,096	4.89
Ottawa loam	do	18.0	Nov. 13, 1943-Jan. 1, 1944	Apr. 21, 1944	60+	6,444	---	4,085	4.34
Florida:	Bellevue Glade	---	---	---	---	---	---	---	---

¹ Field conditions poor and weeding delayed.³ Reseeded.² Sampling inaccurate.⁵ Fertilized twice.⁶ Best stand averaged 2,688 pounds per acre November 1942 and 4,000 pounds September 1943. At Cass Lake best stands averaged 1,846 pounds per acre November 1942 and 3,025 pounds per acre September 1943.

1943 sowing was 4,455 pounds while that for the November sowing was 3,940 pounds.

Samples taken at Edinburg, Tex., on June 2, 1944, gave a calculated weight of 7,579 pounds of roots per acre with the roots averaging from $\frac{3}{8}$ to 1 inch in diameter.

Quality and Utility

A detailed discussion of the quality of kok-saghyz rubber is to be found in a report of the Eastern Regional Research Laboratory, Bureau of Agricultural and Industrial Chemistry (14p).

Laboratory tests on the physical and chemical properties of kok-saghyz rubber showed it to be of such good quality as to justify its

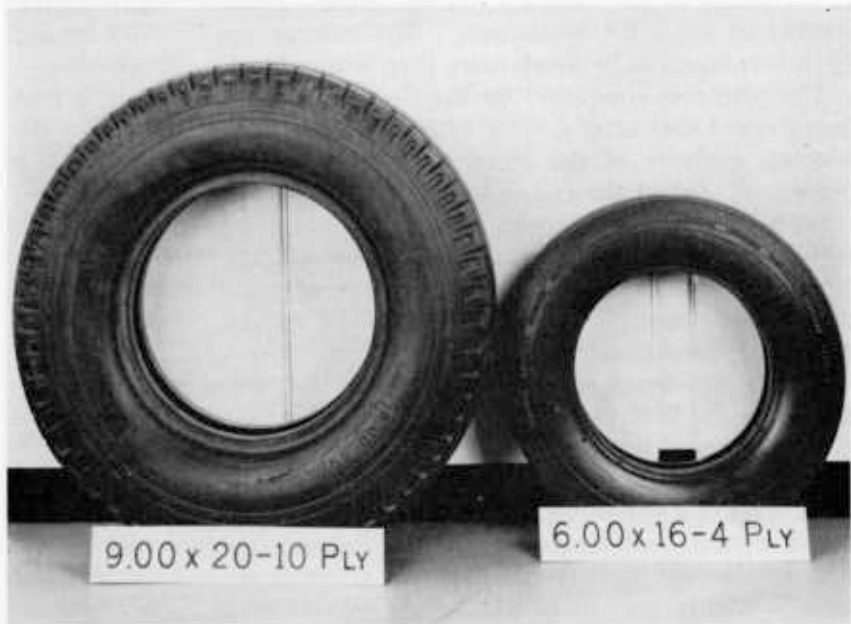


FIGURE 35.—Tires made from kok-saghyz rubber. (Bureau of Agricultural and Industrial Chemistry.)

more complete evaluation through the large-scale commercial fabrication and testing of automobile and truck tires made entirely from kok-saghyz rubber. Contracts were made with the B. F. Goodrich Co. and the United States Rubber Co. to carry out this work using kok-saghyz rubber produced in the pilot plant at the Eastern Regional Research Laboratory.

Fifteen hundred pounds of rubber were shipped to the B. F. Goodrich Co., who fabricated in their regular factory equipment fifty 6.00 x 16, 4-ply passenger car tires (fig. 35). Before processing the rubber, compounding studies were made to determine the proper formulas

and cures for making the various parts of the tire. Some of the experimental tires were given road tests by the B. F. Goodrich Co., in comparison with GR-S tires manufactured by the same company. Others from this lot were sent to the Rubber Reserve Company's Test Fleet at San Antonio, Tex., where four of them were given road tests in comparison with Firestone GR-S controls.

Fifteen hundred pounds of kok-saghyz rubber were also sent to the United States Rubber Co., at Detroit, Mich., where seventeen 9.00 x 20, 10-ply rayon cord heavy-duty tires were fabricated. Four of these were tested under severe conditions with progressively increasing overloads. The test was not continued to the point of carcass failure as the terms of the contract did not permit running the necessary number of miles for breakdown. The mileage required for breakdown was found to be much more than was originally estimated.

The road test conducted by the Rubber Reserve Company's test fleet showed that after driving 17,700 miles at 60 miles per hour, the wearing qualities of the tread on kok-saghyz tires averaged 73.9 percent of that of the GR-S treads. Unfortunately this test is not entirely conclusive in showing the relative wearing properties of kok-saghyz and synthetic rubber tires as the kok-saghyz tires were manufactured by one company with one type of construction, whereas the synthetic controls were manufactured by another company with a different type of construction.

A more significant comparison is seen in the case of road tests conducted by the B. F. Goodrich Co., where similar construction was used in both types of tires.

A later road test made by the Office of Rubber Reserve showed the tread wear of a kok-saghyz tire to be 93.4 percent as good as that of a GR-S control; both tires were made by the same manufacturer. The test was discontinued after 21,848 miles although none of the tires had failed. Eighty percent of the driving was at 60 miles per hour on cross-country highways.

The detailed reports on these fabrication and performance tests can be consulted at the Eastern Regional Research Laboratory, Bureau Agricultural and Industrial Chemistry, Philadelphia, Pa.

The findings of the rubber companies who fabricated tires from kok-saghyz rubber and tested them on the road were that kok-saghyz can be handled with regular rubber tire-manufacturing equipment and with the same techniques as employed for hevea rubber. Its building tack is superior to GR-S and equal to hevea. Its tread wear (with the particular formulas used) was somewhat inferior to that of hevea but superior to GR-S when GR-S control tires had the same construction as the kok-saghyz tires. It can satisfactorily replace hevea rubber in the manufacture of carcasses for heavy-duty tires. GR-S is not

satisfactory for this purpose. Kok-saghyz is superior to any other domestically grown rubber.

Although road tests show that the wearing qualities of tire treads when compounded by an experimental formula (not necessarily the best one) are somewhat inferior to that of hevea treads, this is not particularly significant. Now that GR-S can be made into treads with entirely satisfactory wearing qualities, the big need for high-grade, natural rubber is in the carcasses of heavy-duty tires. This is where kok-saghyz rubber has proved highly satisfactory. If kok-saghyz were available in quantity it could be used in the carcasses, while synthetic rubber is used in the treads, thus making possible the manufacture of heavy-duty truck tires without imported rubber.

ECONOMICS OF PRODUCTION

PRODUCTION COSTS

Such information as is contained in Russian papers refers occasionally to the number of workers required for an individual operation, but no references to the total cost of the production of rubber from kok-saghyz were found.

It was recognized that growing and processing of rubber from kok-saghyz in this country would probably be an expensive operation because of the nature of the plant and the anticipated relatively small yields of rubber per acre. Wartime shortages of labor and equipment would naturally be reflected in the per acre or per pound costs.

No attempt was made to collect cost figures on the various operations included in the 1942 experimental program.

On the basis of available Russian labor estimates and from the limited experience in the 1942 plantings in this country, a prospectus was prepared in January 1943 and presented to the authorities charged with the national program of rubber production (42p). In this prospectus an attempt was made to outline the plan for the emergency production of rubber from kok-saghyz and to forecast the possible cost of this rubber. For such an experimental program as was planned, it was estimated that 50 man-days of labor per acre would be required from land preparation to root harvest and that the small amount of rubber which might be produced the first year might cost as much as \$3.60 per pound. This extremely high estimate of cost per pound included the purchase of all necessary field and laboratory equipment, the construction of a pilot extraction plant, and all phases of experimental work, as well as the predictable direct and indirect costs of growing kok-saghyz.

The importance of accurate cost records was recognized, and for 1943-44, unit costs were kept for each operation as a guide for future operations and as an aid in evaluating kok-saghyz as a rubber crop which could be produced in the United States.

Root Production by Direct Government Operation

Wherever possible suitable land belonging to Government agencies was utilized without cost in the 1943 program. Forty acres of land was secured from the Fish and Wildlife Service in New York State; 100 acres from the Farm Security Administration in Michigan; 4 acres from the Bureau of Animal Industry in Montana; and 27 acres from the Reclamation Service in Oregon.

Before negotiating for suitable lands of representative soil types in the various regions in which it was desired to test the growing of

kok-saghyz, conferences were held with county agricultural agents to discuss the program, coordinate it with the wartime food production program, and to determine fair land valuations and rentals. The land rental program was also discussed with farm groups, cooperative associations, and sugar-beet representatives where such were interested.

In general, farmers were willing to lease part of their land as a patriotic gesture and because they faced a rather stringent labor situation. In Wisconsin the farmer-owner whose land was selected offered his land and his personal services at less than their current value because of a sincere desire to determine the possibility of a new crop in his vicinity where large acreages of drained peat land were undeveloped.

Land rentals generally were based on the intensity of farm use in the locality and the value of specialized crops produced. Except for the Saginaw, Mich., peat area, land secured rent free from other Government agencies proved to be expensive to manage because it was not in good farming condition.

Leases were drawn with fair consideration to the fact that the farmer's crop year did not coincide with the Government's fiscal year. They provided for renewals beyond the close of the fiscal year and for cancellation not later than March 15 to allow the farmer to plan his crop use of the area for the ensuing crop season. These leases worked out to the satisfaction of the farmer-owners and of Government representatives and proved to be equitable.

The decision to liquidate the entire project by June 30, 1944, made it necessary to negotiate termination of some of the leases after March 15 on certain areas leased, but no difficulties arose in reaching satisfactory agreements with the lessors at a direct cash saving to the Government.

Leases of privately-owned land in all areas were made at current local rental rates per acre. The land leased during 1943 ranged from \$5 to \$30 per acre. Generally the irrigated tracts which had been in intensive cultivation for many years carried the highest rental per acre.

Ground preparation costs cover plowing, disking, barrowing, floating, and cultipacking or rolling.

The cost of proper ground preparation varied greatly in accordance with the local practices, local wages, rentals for equipment, kind and type of equipment used, size of the fields, and the number of repeat operations made necessary by reason of weather conditions, failure to secure stands, or excessive weed growth. In general, contract operations handled by farmers cost less than direct Government operations based on Department of Agriculture standardized wages for the locality, an 8-hour day, and overtime pay. Table 10 gives estimated costs of cultural operations for the country as a whole.

TABLE. 10.—*Cost of kok-saghyz ground preparation operations*¹

Operation	Cost per acre (once over) including equipment rental	Acres covered per 8- hour day
Plowing (tractor).....	\$2.00 to \$4.00	3 to 5
Disking (deep).....	.50 to 1.25	10 to 20
Disking (shallow).....	.40 to .75	15 to 25
Spring-tooth harrow.....	.50 to .85	14 to 20
Field cultivator (drying).....	.50 to 1.25	10 to 20
Floating (leveling).....	.25 to 1.25	10 to 40
Spike-tooth harrow.....	.20 to .50	24 to 50
Cultipacker, harrow, or float.....	.50 to 1.25	10 to 20
Rolling.....	.50 to 1.25	10 to 20

¹ The total average over-all ground preparation costs, including additional disking, harrowing, floating and so forth to secure a fine seedbed, would probably run \$6 to \$15 per acre in an average year.

Ground preparation for the 1943 season ranged from \$3.05 to \$38.07 per acre, the lower figure representing the cost on a field which had been partially prepared before being leased by the Government, in which case the rental costs reflected work done by the owner in partially preparing the seedbed. Some differences in ground preparation costs are the result of differences in the previous use of the land.

The wide variation in cost of land preparation was largely due to the attempt to prepare peat land which had not been previously cropped. The cost of ground preparation on the Gleason peat field at Aitkin, Minn., which had been well "subdued" by previous cultivation, was \$12.21 per acre, while costs on the Stapp field which had previously had but one crop, flax, were \$15 per acre.

While it was not known that fertilization was a definite requirement of kok-saghyz culture on the lands selected, 1942 experience indicated that it might be a profitable practice at least on some soils. The fertilizers applied in 1943 cost from \$6.19 to \$31.75 per acre.

Seeding in multiple rows, including the treatment of seed and the reseedling of failed portions, ranged between \$2.75 and \$6.24 per acre.

Cultivation is a relatively low-cost job, and early, frequent, and careful cultivation resulted in a considerable reduction in the weeding cost. For the 1943 season cultivation costs ranged from \$6.49 to \$32.66.

Weeding proved to be the most expensive operation in growing kok-saghyz. As no mechanized method of removing weeds very close to the small plants and within the rows was known all weeding was done by hand. Weeding costs can be reduced by careful preparation of the ground, including summer fallowing, delayed seedings, early and careful cultivation, and by the use of hand-weeding tools.

It is probable that maximum efficiency and minimum weeding

costs can be obtained by paying workers on a piece-work basis. At Plainfield, Wis., weeding was contracted to the farmer-cooperator who had imported a crew of Jamaicans. The contractor paid this labor on a per row piece-work basis. These workers made more money per day (some by putting in longer hours) than regular hourly workers but the cost per acre was considerably less. Weeds in this area were probably as plentiful as in any field elsewhere. The total actual cost of four complete weedings was \$101 per acre.

At Crookston, Minn., on heavy mineral soils, weeding costs averaged \$150 per acre and ranged from \$60 per acre on a late-sown tract where the early weeds had largely been eliminated before reseeding to \$300 per acre where weeds were most numerous and early cultivation was impossible due to wet soil. At Moorhead the average cost was \$124 and ranged from \$56 to \$191 (30p). Here again, the low cost was on a late-seeded area where weeds were destroyed by ground preparation prior to seeding and where cultivation and weeding could be performed at the proper time.

In Montana hand weeding (four times) averaged \$223 per acre and was in addition to cultivation (four times) costing \$11 per acre and hand hoeing (four times) costing \$12 (6p). Weeding costs varied from an average of \$172 per acre for single rows spaced 20 inches apart to \$182 for double rows 9 inches apart, with a 24-inch free space between double rows, and \$254 for triple rows.

In Oregon (9p) there were relatively few weeds on mineral soil; more on the peat. Weeding costs averaged \$96 per acre on the mineral soil and \$179 on the peat. Stands were very light with many open spaces which reduced the hand-labor costs for the later weedings.

Probably the most difficult labor situation was in New York State where truck crop and fruit-growing operations, industrial development, and the construction of a military camp nearby had drained all surplus labor. Failure to recognize this situation early in the season and to start recruiting well in advance of the closing of schools left the project without sufficient labor. Oliver (31p) reports that weeding on the Pease field should have been done by June 4, but no labor was secured until June 18, and then only 7 inexperienced high school boys were on the job. By that time weed growth was excessive and much damage was done to the stand in removing the large weeds. Tractor cultivation had not been started because the indistinct rows were hard to follow. Late in June a contract for weeding labor on an hourly basis was arranged. Most of the Pease field was weeded 3 times; and one section of about 2½ acres was weeded a fourth time. The first weeding required 33.6 man-days per acre, the second 41.6, the third 6.8, and the fourth 7.1. The total cost of weeding was

nearly \$600 per acre. Similar difficulties were encountered on the late-seeded Rogers tract and the cost was nearly \$300. Even so, an inspection in early October showed many weeds in this field.

Weeding costs at Burlington, Vt., were also high, averaging \$417 per acre.

While the practice of thinning or blocking to establish the desired density within the row was not generally recommended in 1943, certain fields were thinned to determine the value of this operation and the cost. (These costs are not included in table 12.) Zehngraff (*45p*, *46p*) kept records on the cost of various thinning jobs. The lowest cost, \$27.90 per acre, was in 4-inch blocking with a hoe. Hand thinning costs on a per-acre basis varied from \$54.25 for 5-inch spacing to \$76 for 3-inch spacing and \$180 for 2-inch spacing.

The cost of the various operations connected with harvesting, topping, lifting and picking, storage, drying, baling and sacking, washing and loading on cars, varied greatly with the location, the equipment used, the amount of hand labor required, method of drying employed, weather conditions, and other factors. Table 11 is a summary of the harvesting costs of the 1943 program. The table reflects the greatly reduced cost of mechanized topping, and also emphasizes the relatively low cost of root lifting at Cass Lake where the soil was sufficiently light and sandy to permit operation of the digging machine with discharge of the roots onto a cart, thus eliminating hand picking. It is apparent that a fully mechanized operation of topping, digging, and picking would greatly reduce costs.

Root harvesting will be an expensive operation until harvesting machinery can be perfected. Improvements must also be made to secure a greater efficiency in root harvest, that is, to recover practically 100 percent of the roots in the upper 8 to 10 inches of soil.

Reduction in costs may come from use of a machine which will top, push the tops to one side of the row, lift, shake the soil from the roots, and deposit them on a cart or in a crate. Sufficient work has been done to warrant the assumption that such a machine can be perfected without great difficulty during the early stages of any expansion program.

Estimated washing costs are based on the assumption that all roots should be washed immediately following digging and that the demonstrated washing principles can be extended to large scale mechanized washing. Washing, if required, may not be done until the roots reach the mill.

Drying of roots is essential for year-long operation of an extraction plant and if the salvage of fermentable sugars is to be a part of the program. Eskew (*14p*) reports rubber from rotted or retted roots to have green tensile properties above the average but to be more sub-

TABLE 11.—*Cost of root harvesting, fall 1943*

Location and soil	Per acre			Per ton (green weight)				
	Topping		Digging and lifting ¹	Pit storage	Drying and storage	Baling or sacking	Washing	Loading
	Hand	Machine						
Minnesota:	<i>Dollars</i>	<i>Dollars</i>	<i>Dollars</i>	<i>Dollars</i>	<i>Dollars</i>	<i>Dollars</i>	<i>Dollars</i>	<i>Dollars</i>
Cass Lake, sandy	13.74		² 26.07		³ 8.44	⁴ 7.75		0.51
Moorhead, loam		3.04	⁵ 62.23	3.93	⁶ 38.86	⁷ 2.89		.61
Crookston, silt loam	14.82	2.23	⁸ 117.00		⁹ 31.63	⁴ 7.75		.51
Michigan:								
Saginaw, muck	37.57	.90	¹⁰ 81.70	.46	¹¹ 58.00		3.00	4.62
Manistique, sandy	11.94		32.86		³ 16.77	⁷ 5.86		.51
Wisconsin:								
Plainfield, peat		1.60	¹² 42.08					
Montana:								
Missoula, loam	81.05		72.54		³ 23.49			
New York:								
Seneca Falls, loamy fine sand	11.03		89.20		¹³ 25.91			

¹ Includes hauling to storage.² 95 percent roots recovered by modified potato digger.³ Air-dried.⁴ Baled.⁵ 55 percent of roots recovered by modified potato digger.⁶ With corn drier.⁷ Sacked.⁸ 81 percent of roots recovered by modified beet lifter.⁹ In heated building.¹⁰ 78 percent of roots recovered by modified potato digger.¹¹ Partially heated building.¹² 76 percent of roots recovered by modified potato digger. Does not include \$6 hauling cost.¹³ In unheated building.

ject to rapid deterioration on aging than rubber obtained from undecomposed roots. Furthermore its extraction is difficult and unpleasant. In addition the fermentable carbohydrates are lost in rotting. It appears doubtful that the cost of drying can be justified simply to salvage the sugars unless the cost of this process can be materially reduced. Crude methods of drying roots, such as were employed in the fall of 1943, are undoubtedly impractical because of slowness in drying and the large drying capacity required.

Baling of dried roots is necessary to reduce storage space and to facilitate transportation and handling from storage to the extraction plant. Even for storing baled dried roots extensive storage facilities will be essential in connection with year-long operation of the extraction plant. It is probable that mechanized handling of dried roots to the balers and mechanized baling will result in great reductions in the costs indicated in the limited hand operations of 1943. No accurate cost figures were obtained for drying, storing, or incidental handling operations.

The cost of producing kok-saghyz on an acreage basis varied as to the locality with land rentals, wage schedules, size of field, row spacing, machinery and equipment used, climatic conditions, weediness of the field, amount of hand labor required, and many other factors. The basic cost per acre of growing kok-saghyz will eventually

reach a constant level for any given locality. The cost of producing a pound of seed or rubber will then vary in accordance with the yield secured.

Factors affecting root volume per acre and rubber yields include the physical characteristics of the soil and its fertility, the time of sowing, together with the length of the growing season, the density of the stands, and the efficiency of the harvesting operation.

Table 12 is a compilation of minimum and maximum field production costs in 1943, together with an estimate of average production costs which might be anticipated in any future program of production using *unimproved* seed, employing cultural methods as now known, and growing the plant in the same general areas. In compiling the minimum and maximum 1943 production costs, no consideration was given to the costs in Vermont, New York, and Oregon where the effort failed in whole or in part. The table does not include overhead costs, which obviously must be incurred in organizing and developing any program.

TABLE 12.—1943 and estimated future per acre field production costs for 1-year kok-saghyz plantings (After Wales, 42p)

Operation	1943 costs		Estimated average future costs			
	Minimum	Maximum	Lake States		Irrigated West	
			Mineral soil	Peat		
	<i>Dollars</i>	<i>Dollars</i>	<i>Dollars</i>	<i>Dollars</i>	<i>Dollars</i>	
Land rental.....	5.00	30.00	10.00	20.00	30.00	
Ground preparation.....	¹ 3.05	38.07	9.00	11.00	15.00	
Fertilizer.....	6.19	31.75	13.50	21.50	13.50	
Sowing, including presowing treatment and re-seeding.....	2.75	6.24	3.00	3.00	4.00	
Cultivated 4 times.....	6.49	32.66	6.50	6.50	10.00	
Weeded 4 times.....	² 101.62	² 274.11	120.00	140.00	150.00	
Irrigation.....		65.76			60.00	
Root harvesting:						
Topping (machine).....	² 1.60	4.82	25.00	25.00	35.00	
Lifting (machine).....	49.68	81.70				
Washing.....		3.00				
Drying.....	25.00	50.00	15.00	15.00	20.00	
Baling, storage, and loading.....	7.43	21.76	14.00	14.00	18.00	
Insect and disease control.....		.86	.50	.50	.75	
Total.....	208.81	640.73	219.50	259.50	360.25	
Roguing.....	6.16	21.00	12.00	12.00	12.00	
Seed collection.....	9.48	38.00	45.00	45.00	60.00	
Seed drying, threshing, and cleaning.....	2.80	16.74	10.00	10.00	13.00	

¹ Part of the preparation already done when the land was leased.

² Wide deviations from these costs have not been included.

Cost of Extraction

Estimates of the cost of recovering rubber from kok-saghyz roots have been prepared by the Eastern Regional Research Laboratory of the Bureau of Agricultural and Industrial Chemistry.

The root-milling portion of any factory for recovering rubber from kok-saghyz is more costly than that for rubber-processing. Therefore, the design and estimate of the cost of the factory have been based on a constant rate of handling roots rather than on a constant rate of rubber output. The factory, as designed, would turn out an average of 10 long tons of rubber a day operating 12 months a year.

In preparing these estimates it has been assumed that one-half of the kok-saghyz acreage required to support a single processing plant would be harvested in October and November, and the balance during the spring months. The proposed factory includes a drying plant to prepare, during each of the harvesting periods, a supply of roots to keep the plant in operation until the next harvest is under way.

For the purpose of estimating the initial cost of the factory and the cost of operations, the average rubber content of the roots harvested in the fall of 1943 and processed during the early spring of 1944, 5.25 percent, has been used to arrive at the cost of extracting rubber from freshly harvested roots. As a measure of the increased rubber production from roots harvested in the spring and the decreased cost of operations, the average of those lots harvested during March, April, and May 1944, 7.50 percent, was used.

Operating costs are based on the assumption that the roots will be washed in the field, dried to a moisture content of 30 percent before delivery to the factory, and further dried to 15 percent before storage at the factory.

The carbohydrate content of fall-harvested roots is assumed to be about 38 percent, on a moisture-free basis, and of spring-harvested roots, 11 percent, the latter being so low that recovery would not be attempted. The credit for fermentable carbohydrates in the leach-liquors from fall-harvested roots has been calculated on the basis of 2.7 cents per pound of carbohydrates, using labor and equipment costs as they prevailed during the 1944 pilot plant run.

The complete cost of the factory, including erection and engineering expense, is estimated on the basis of high wartime costs of labor and materials at \$2,800,000. The average year-round cost of recovery of rubber from roots delivered at the drier, including interest and amortization, would be about 11.0 cents per pound of rubber. This figure assumes a credit averaging 5.7 cents per pound of the total yearly production of rubber, for the fermentable carbohydrates recovered from the fall-harvested roots.

Improvements in kok-saghyz seed strains, which can be expected to give larger roots of higher rubber content, and the development of better field practices resulting in larger yields of roots would correspondingly decrease the initial cost of the factory and reduce the per pound cost of extracting rubber from the roots.

The following tabulation gives the estimated factory costs per pound of commercial rubber produced and the details of direct processing costs:

	<i>Fall-har-vested roots (cents)</i>	<i>Spring-har-vested roots (cents)</i>	<i>Weighted average (cents)</i>
Estimated factory costs per pound of commercial rubber produced:			
Fixed charges (interest 5 percent, amortization 8 percent, taxes 2 percent, insurance 0.5 percent) ..	7. 83	5. 49	6. 46
Direct processing costs	11. 90	9. 05	10. 24
Total manufacturing cost	19. 73	14. 54	16. 70
Credit for sugars	-13. 78	0	- 5. 68
Net manufacturing cost	5. 95	14. 54	11. 02
Direct processing costs:			
Labor, including maintenance:			
Root drying and storage	1. 37	. 93	1. 09
Root processing in factory (through primary screening)	4. 37	3. 15	3. 69
Rubber processing	1. 42	1. 06	1. 21
Supervision and management .....	. 45	. 34	. 39
Coal for root drier .....	. 32	. 23	. 26
Water supply .....	. 10	. 09	. 09
Steam .....	. 77	. 56	. 64
Purchased power for:			
Root drying and storage .....	. 12	. 08	. 11
Root processing .....	. 97	. 72	. 82
Rubber processing .....	. 41	. 41	. 41
Pebbles and other supplies	1. 60	1. 48	1. 53
Total	11. 90	9. 05	10. 24

A complete summary of the extraction studies and pilot mill operations, including detailed cost estimates, can be found in a paper to be published by R. D. Eskew, Eastern Regional Research Laboratory, Bureau of Agricultural and Industrial Chemistry.

Seed Production by Direct Government Operation

The production of a supply of kok-saghyz seed was one of the major objectives of the 1943 program and would be a major item of cost in any expansion program.

It is probable that in the future seed production would be confined to the most favorable seed-producing localities. During 1943, seed was collected in the Lake States, Montana, and Oregon. Consequently, cost records include the less economical collection of the seed in the Lake States and on the Pacific Coast, as well as the more favor-

able production of kok-saghyz seed in the irrigated mountain valleys of Montana.

The range of costs for land rental and ground preparation, fertilization, weeding, cultivation, and seeding is the same for seed production as for root production. To these costs then must be added the cost of those operations chargeable directly to seed collection.

Many factors, including the density of the planting; the percentage of first- and second-year flowering plants in the stand; location and climate as they control the photoperiod; weather conditions which influence the spring seeding season; and the growth during the season and especially wind and rain during the seed-ripening period; the presence of pollinating insects; and the efficiency of the seed-picking, threshing, and cleaning machinery, all have a direct effect on the yield per acre and therefore upon the cost per pound.

The most economical method of seed production is to collect seed in the second year from stands of second-year flowering plants segregated in plantings made and maintained especially for seed production. This would result in obtaining higher yields of purer, better quality seed and would relieve farmers engaged in kok-saghyz production from rubber of seed-collection details. However, in any emergency requiring rapid expansion of seed supplies, seed would have to be collected from every available planting.

A seed-collecting machine will handle about 8 acres per day. The period of operation may extend for 50 to 60 days. In 1943 seed-collection costs ranged from \$9.48 to \$38 per acre.

Since more attention must be given to roguing in connection with seed production than with root production, the cost of roguing is important in connection with seed-production costs. In 1943, roguing costs ranged from \$6.16 to \$21 per acre, the wide variation resulting from differences in the amount of rogue seed in the initial supply of kok-saghyz seed. At least two rougings were made the first season in all fields from which seed was collected.

For several years it is probable that roguing costs will average from \$10 to \$12 per acre for stands in which the rogue content does not exceed 1 percent.

Inasmuch as seed drying, threshing, and cleaning operations in 1943 were directed toward developing proper methods of accomplishing this work, the costs, ranging from \$2.80 to \$16.74 per acre, have little meaning. Estimates of future seed drying, threshing, and cleaning costs based on handling a much larger amount of seed might range from \$10 to \$13 per acre.

Experience in 1943 indicated that irrigation greatly increased yields of seed and consequently reduced the cost of seed per pound, justifying the high expenditure involved in using irrigated land.

Wage Rates

Wage rates varied with the locality and usually depended on the availability of labor and the demand for it. Table 13 shows the wage scale used on the kok-saghyz project in 1943. An endeavor was made to adhere closely to the prevailing wage scale for farm labor used in the vicinity of kok-saghyz planting areas. In general wages paid were slightly higher because of the application of the Federal overtime law. The initial rates had been determined in conference with county agricultural agents, beet-sugar companies, farm associations, and individual farm employers of labor.

Not only does the agricultural wage scale affect costs directly, but, particularly in wartime, it determines the class of labor which can be hired. In the Lake States it was necessary to use untrained women and high school students, except at Saginaw, Mich., where Mexican nationals were available because of the failure of farmers to seed their contracted acreage of sugar beets.

At Saginaw whole families of Mexican nationals were employed. Most of them did not speak or understand English and it was necessary to do all training and supervision through interpreters, many of whom were not capable of interpreting and understanding the instructions. However, all of the laborers were accustomed to weeding sugar beets.

TABLE 13.—*Wage rates per hour, including overtime, by class of labor*

State	Class of labor			State	Class of labor		
	Common	Straw-boss	Farm laborer (skilled)		Common	Straw-boss	Farm laborer (skilled)
	<i>Dollars</i>	<i>Dollars</i>	<i>Dollars</i>		<i>Dollars</i>	<i>Dollars</i>	<i>Dollars</i>
Minnesota.....	0.50	0.575	0.65	Oregon.....	0.645	-----	0.80
Michigan.....	.50	.62	.82	New York.....	.62	-----	.80
Wisconsin.....	.375	.50	.563	Florida.....	.50	-----	-----
Montana.....	.473	.78	.85				

Coster (*6p*) in Montana, was able to hire women accustomed to farm work and found it unnecessary to employ students who required excessive supervision.

Department of Agriculture regulations did not allow a differential in wage scale between experienced and inexperienced labor and between adult labor and youth labor. After being trained and gaining a little experience, a few school children did as much or more work than some of the adults, but on the whole, the cost of weeding and other operations was decidedly increased because this class of labor had to be paid the same rate as experienced adult labor.

Contract Growing of Kok-saghyz

Contract growing of kok-saghyz by farmers was studied on a limited scale during 1943 and plans were made to contract for the production of small acreages to several farmers in the 1944 program. Generally the 1943 program was handled directly by employees of the Government on land leased from the farmers or secured from cooperating agencies. In all of the areas some of the operations, particularly ground preparation, were contracted to farmers.

At Plainfield, Wis., the farmer-lessor handled all of the cultural operations except roguing and seed collection on the basis of individual contracts entered into prior to undertaking any specific job. This particular owner farms some 3,000 acres of peat land and specializes in the production of potatoes, onions, table beets, and carrots. He imports about 60 laborers annually to handle most of the hand labor although he also employs local labor. This man was familiar with cultural operations which proved adaptable to the growing of kok-saghyz and hence was able to estimate closely on the cost of cultivation, weeding, lifting, etc. Practically all of the labor used by this farmer was paid on a piece-rate basis, the laborers making good wages, although some of them worked long hours. The piece-rate method of payment for services secured a maximum output per day and close supervision and inspection by the project superintendent made certain that an acceptable job was done. If not, the laborer had to go back and make it satisfactory before receiving payment.

In any large production program undertaken in the future, primary dependence probably would have to be placed on farmer production under suitable contracts.

Contracting the production of agricultural crops is done annually by beet sugar companies, canneries, and other processing plants. Knutson (24p) discusses the possibility of contracting labor for the growing of kok-saghyz and has included samples of the sugar-beet contract forms with his report. For a new crop such as kok-saghyz it might be necessary to include in the contract some of the specifications for growing the crop, particularly as to seed and seed treatment, rate of sowing, weeding, roguing, and harvesting. Careful instructions for the guidance of the farmer-contractor and adequate inspections would be essential in order to make certain that a good crop was produced. This would require well-trained and qualified men to handle the preparation of contracts, instruct the farmers, and inspect the fields adequately.

Experience with sugar-beet production indicates that, as a rule, labor services and the purchase of new equipment during the growing

season must be financed by the parent organization for whom the crop is produced. It is probable that contract production of kok-saghyz would have to be financed in the same way.

If a program large enough to give the maximum tonnage of roots for a centrally located extraction plant were undertaken, problems of labor and finances would immediately become of great magnitude. Some of the field work could be done by the farmer as a part of his farm operation, but the hand labor involved would be an extra requirement. Primary dependence would have to be placed on imported labor such as Mexican or Jamaican nationals, just as the beet sugar companies import labor for the hand work in connection with sugar-beet production. Adequate housing would have to be provided either as individual family homes or as large camps. If centralized camps were used, transportation of the labor to and from the farm would be required.

The amount and kind of farm machinery suitable for large-scale production of kok-saghyz and which is normally available on the farms in the general territory where kok-saghyz could be produced in case of any expanded program, is necessarily dependent upon the kind of crops being produced in that area and the intensity of agricultural practices. Walley (43*p*) reports that ground preparation machinery is generally available. In some localities farms lack the necessary cultipackers or land rollers and these would have to be purchased. Adaptable cultivators are probably available where sugar beets, chicory, onions, carrots, and similar crops are grown, but even here specialized attachments would have to be provided to secure the careful work required during the early life of the weak kok-saghyz seedlings.

Although Russian papers (2, 66) suggest the possibility of using sugar-beet drills and grain drills to sow kok-saghyz, American experience has been that these implements are not readily adaptable to the sowing of this very small seed. Better results were secured by the use of drills adapted to the sowing of fine seed. Only those few farmers specializing in the production of carrots and similar root crops own suitable multiple-row seed drills.

The seed collecting and root harvesting equipment is new equipment devised and constructed for specific use with kok-saghyz, hence would not ordinarily be available.

Payment on an acreage or a cost-plus basis does not appear logical since too many factors affect yield. With a new crop on an emergency basis the farmer ought to be entitled as a minimum to his out-of-pocket costs of production plus a reasonable rental for machinery and land. Payment on the basis of fresh weight of the roots is

illogical since roots lose weight rapidly on exposure to the air, the amount varying with exposure and weather conditions.

The best method of payment would seem to be on the basis of the rubber content of the roots on a dry weight basis. This would require adequate sampling of each load delivered, weighing each sample and deducting for tare, including the weight of soil attached to the roots. This sample would then be analyzed for rubber content and the rubber content of the load could be calculated. Such a procedure would require a considerable number of men including analysts.

MANPOWER REQUIREMENTS

It was recognized that, at least in the first years during which kok-saghyz might be grown in this country, the availability of labor might be a controlling factor in the production of rubber. Therefore, records were kept to determine the amount and type of labor, particularly hand labor, employed in 1943 and which might be required in any future operations.

Insofar as peak manpower requirements are concerned, kok-saghyz is one of the most exacting of all farm crops; for two field operations, weeding and harvesting, must be performed largely by hand. Development of harvesting machinery may reduce the excessive hand-labor requirements of the root harvest.

During 1943 the labor supply was scarcely adequate anywhere except possibly at Missoula, Mont., and Burlington, Vt., where only small acreages were sown. Adequate labor was obtained where recruiting was properly organized early in the season before the actual need for hand labor developed.

The Saginaw, Mich., fields were located near a highly industrialized area and only a few local workers were hired. Fortunately, a beet sugar company operating in this area had imported Mexican laborers and their families but because of the cold backward spring, farmers were able to sow only 30 to 40 percent of the contracted beet acreage and the company was pleased that the kok-saghyz project was able to employ many of their laborers. However, in these arrangements beet work had preference over kok-saghyz and at times laborers had to work in beet fields when the kok-saghyz needs were critical.

The labor situation in all of the root harvesting areas was extremely difficult in the late fall of 1943. In Minnesota students had returned to school and kok-saghyz harvesting was in direct competition with the farm labor requirements for harvesting potatoes, onions, sugar beets, etc. On these farms labor was hired on a piece-rate basis and workers soon learned that earnings under the piece-rate system were higher than the established daily wage being paid

on the kok-saghyz project. Most of the labor on these regular farm operations was well paid and seemed to prefer to lay off rather than work under the cold wet conditions on the kok-saghyz fields at a daily rate of pay.

At Saginaw, Mich., most of the Mexican labor imported by the beet sugar company had returned to Mexico before the kok-saghyz harvest was begun. Those who remained were still working in the sugar-beet fields in an endeavor to complete the lifting and topping job for the beet farmers before freeze-up. It was difficult to maintain a crew of local workers.

At Plainfield, Wis., the Jamaicans imported by the farmer-owner who had contracted for the kok-saghyz harvest found it difficult to work under fall temperature conditions much colder than those to which they were accustomed. On cold, cloudy, wet days these laborers refused to work in the field and on the few intervening warm days their services were required by the farmer to save his own crops. School children were transported 25 miles on two separate occasions in an effort to pick up all of the roots before a freeze-up.

No great difficulty was experienced in the spring of 1944 in securing labor to handle the reduced acreage. However, in Minnesota the supply of skilled farm labor was lower than in 1943 and it would have been impossible to have carried on an expanded program without serious conflict with farm labor requirements. At Plainfield, Wis., practically no labor was available until after school was out at which time it was possible to hire a few high school boys. The imported Jamaican labor did not arrive until June 1. It would have been impossible to have conducted a harvesting program unless the entire operation had been on a mechanized basis.

At Saginaw, Mich., labor for the spring work of 1944 was available when needed. A number of Mexican families had moved back to the locality and were not needed in connection with sugar-beet culture until after the spring harvest of kok-saghyz had been completed. Milnes (29*p*) states it would have been very difficult to secure labor for an expanded program in 1944.

At Missoula, Mont., the labor situation was reported to be about the same as it was in 1943. Coster (7*p*) estimates that labor could have been hired to handle up to 100 acres in the vicinity of Missoula. However, at Miles City the situation was more critical. There were but few men not in military service and students were not available until after school closed.

At Klamath Falls, Oreg., Dill (10*p*) reports it was possible to secure labor but that turnover was high. He hired three different crews between May 1 and May 27. In June a small group of high

school students was hired. They continued to work until the close of the project and did a better job than local farm labor.

In view of the difficulties experienced in obtaining labor when needed for the relatively small experimental plantings of 1943, it is doubtful whether a program of kok-saghyz rubber production of a size large enough to contribute significant quantities of natural rubber could have been undertaken without serious conflict with the wartime food production goals.

The weeding requirements may be taken as an example of the peak labor demands. Knutson (24*p*) indicates that, in the Red River Valley, labor at the rate of $1\frac{1}{2}$ persons per acre must be employed to weed. In Michigan, Milnes (28*p*) working on very weedy peat soil suggests a minimum of 3 persons per acre for the first weeding and thereafter labor at the rate of $1\frac{1}{2}$ persons per acre can keep abreast of the job. Dent (9*p*) in Oregon, also operating on very weedy land, indicates that 3 to 4 weeders per acre must be employed.

The farmer-contractor who handled the weeding job at Plainfield, Wis., had 60 laborers employed and it is understood he placed his entire crew on the kok-saghyz weeding job. This crew, averaging $1\frac{1}{2}$ men per acre, was unable to keep abreast of the job and in some cases the weeds were 4 to 6 inches tall before being pulled. Part of this difficulty may be attributed to the fact that the farmer also had other crops to weed and there may have been some delay in reaching the kok-saghyz fields for the additional weedings.

Coster (6*p*) does not indicate the manpower requirements for Montana. He does indicate that weeding must start within 2 to 3 weeks after seeding and be repeated at 2-week intervals. This would mean that each field must be covered within 12 working days.

Based on the 1943 record and the opinion of those in close contact with the work, it is safe to assume that labor at a minimum of $1\frac{1}{2}$ persons per acre must be available during the peak of the weeding season. At Saginaw weeding was spread over a considerable period and even though more than $1\frac{1}{2}$ man days per acre were employed, Milnes (28*p*) found it necessary to employ the crew 10 hours a day 7 days a week. Even then he lost a portion of the seeded area because of weed growth.

The manpower requirements for the various cultural and harvesting operations are so great that most rural areas could furnish only a small fraction of the total labor required to produce any considerable amount of kok-saghyz rubber. Production of enough kok-saghyz roots to keep an extraction plant in operation would require moving large numbers of laborers into planting areas and providing the necessary housing.

EQUIPMENT AND MATERIALS REQUIREMENTS

In preparing the prospectus (42p) the project requirements for farm implements and critical materials were estimated as closely as possible on the basis of the very incomplete available information. The program was approved for 750 acres so that experimentation and research might be conducted on a field scale.

In general, equipment supplied in accordance with the estimate was sufficient. However, during the course of the program it was found that the division of the total acreage into fields located at some distance from each other served to increase the requirements during particular seasons. Because of the many rainy days during the time when ground preparation and sowing were in progress, it was not possible to work all of the fields at exactly the proper time. One way to decrease the amount of equipment required for any large program would be to equip tractors with lights to permit 24 hour operation. Such lighting equipment was not available in 1943.

In the development of any large program the expansion most likely would be gradual. It is anticipated that, ultimately, a total of about 63,000 acres would have to be in production to supply a central extraction plant (14p). Presumably such a program would be contracted to a large number of farmers, each of whom would have some equipment available. However, each of these farmers would also have his own farm work to carry on so that his equipment could not always be made available at the proper time for kok-saghyz operations.

It is assumed that the normal complement of farm tractors, plows, disks, harrows, and cultivators on farms in areas where kok-saghyz would be grown would partially fill the requirements of a large kok-saghyz program, but additional equipment would have to be purchased.

Kok-saghyz production requires a fairly definite schedule of ground preparation, seeding, and cultivating. These operations cannot be delayed in order to plow and plant corn or other crops at the proper time. Ground preparation, for example, is a job that must be performed fully and completely in a careful manner to insure moisture capillarity and germination of the seed. To delay sowing when the ground has been prepared may make it necessary to do part of the preparation work over again. Moreover, if the area is not completely seeded immediately following preparation, an intervening rain may make reparation necessary.

The fact that kok-saghyz culture requires intensive operations within limited time periods and that the plant demands more cultivation and attention than most other farm crops makes the equipment and material requirements for growing kok-saghyz appreciably higher than those for other crops.

The work of the project did not proceed far enough to provide any basis for accurate estimates of space and materials requirements for drying, storing, and processing roots. Such figures on equipment and materials requirements as are included in Wale's report (42p) were based upon estimates for emergency production of kok-saghyz as an independent crop to produce the maximum amount of rubber in the shortest possible time during the critical period. These estimates are undoubtedly far higher than the requirements of any long term non-emergency operation which might be gradually fitted into the agricultural development and general economy of the region.

Crops most likely to be displaced by kok-saghyz would be chiefly corn, small grains, potatoes, sugar beets, onions, table beets, carrots, and other vegetables.

On the basis of information developed in 1943 and 1944, it is estimated that the unselected seed available would have been sufficient in amount to produce 20,000 tons of rubber on a total of from 300,000 to 400,000 acres in one year. Actually such an extensive program was never given serious consideration. Such progress as has already been made in improvement of the plant would greatly reduce the acreage required.

It appears probable that, for the country as a whole, kok-saghyz would not seriously displace any of the major food crops except possibly in those localities which specialize in the production of potatoes, sugar beets, and similar crops. The impact of kok-saghyz production on food production is given further and more detailed consideration in Walley's report (43p).

IMPROVEMENT OF THE PLANT

INCREASED RUBBER YIELD

The seed of kok-saghyz received from Russia and planted in this country in 1942 produced plants which showed variation, the extent and character of which revealed it to be, at least in part, hereditary in the case of root weight, root form, rubber content, seed size, leaf form, flowering habit, and other characteristics.

The Russians had recognized the extent of this variability and its significance in relation to the problem of producing a vigorous high-yielding plant. Koroleva (20) reports that in a study of variation made in 1935 root weights in comparable plantings were found to range from 2 to 150 grams, rubber percentages from a trace to 30 percent and seed weight from 0.25 to 0.80 gram per thousand. A selection program, aimed toward improvement of the plant, was begun in that year. Selection was based mostly, first upon size of root, and then upon rubber percentage, although simultaneous selections based upon root size and rubber percentage were made.

By the first method, four years' selection produced considerable improvement in average rubber content over the selected plants used as parents in the experiment. By 1940 two strains selected simultaneously for root size, rubber percentage, and seed size produced roots with average weights of 24 and 25 grams, rubber percentages of 14.5 and 15.5, and seed weighing 0.50 and 0.58 gram per thousand respectively.

Koroleva also reports a program of mass selection on the basis of flowering habit. It was discovered early that plants which did not flower in the first season generally produced heavier roots during the first growing season than those which flowered within 85 days of sowing. Rubber percentage was found to vary considerably in both groups, with the average so nearly equal that non-first-year-flowering plants yielded considerably more rubber per acre. Mass selection of second-year-flowering plants actually raised rubber production on a per acre basis considerably. Koroleva points out that failure to flower in the first year may be due to environmental factors as well as to the inherent characteristics of the plant.

Koroleva also discusses variations in leaf shape as possibly related to root size, rubber content, and other important characteristics. During the vegetative period there is considerable variation in the

successively formed leaves. As leaves are continually formed, matured, and dropped off, the appearance of the plant undergoes a series of changes as to leaf shape. The extent of this change is less in plants which do not flower the first year than in those which do. In the first-year-flowering plants it is so great as to preclude the use of leaf shape as the principal character by which to select desirable plants.

Among non-first-year-flowering plants Koroleva selected, at the end of the first season, two types which seemed most promising as to root weight and rubber content: (a) Plants with entire margins, (b) plants with sharply incised (*pinnately cleft*, according to Koroleva) leaves. She indicates that the first group occurs seldom but that the progeny are rather uniform as to leaf shape. Mass selection of plants with the second leaf type isolated a population with a 16-percent rubber content.

Koroleva emphasizes that leaf form is in a large measure dependent upon density of the stand and other environmental conditions and that it is of limited use as a basis for selection.

The observations of several other Russian investigators are reviewed by Krotkov (21). Their later work was directed less toward improvement of the plant by methods designed to isolate plants of superior hereditary constitutions and more toward the study of the effects of seed treatment, vernalization, and improvement of cultural methods.

The seed which the Russians shipped to this country in 1942-1943 was obviously not of improved strains. The nature of reproduction in kok-saghyz is such that it is quite possible that domestication of the plant and production of seed in large plantings without selection may have reduced the quality of the seed as compared with that originally selected from the wild.

The tremendous genetic variation among the plants grown from this seed gives promise of startling results from a plant improvement program. Both selection and breeding, and a combination of the two, were begun in this country as soon as the nature of the plant had been well enough worked out to indicate the potentialities of and limitations to improvement, and the proper methods and procedures to be employed. The Florida plantings which are discussed elsewhere in this report were made primarily for the purpose of speeding up plant improvement operations by providing an additional generation each year. There was some hope that small plantings made in Chile and Argentina would serve the same purpose. While such work has been on a limited scale, marked improvement of kok-saghyz can be expected within a few years.

Selection has been of both individual roots and classes for particular characteristics. Selections have been based on root size, root form, rubber content, flowering habit, and general vigor, in addition to other characteristics about which information is essential to a genetic study.

The usual procedure of selection followed by crossing to combine desirable characteristics, selection of progeny, and stabilization of pure breeding strains is considerably complicated in kok-saghyz by the presence of self-sterility factors. A few plants, which are self-fertile, at least at certain periods, have been found and it may be that eventually self-fertility can be obtained in an otherwise desirable strain.

Another possibility is the establishment in more or less permanent plantings of selected plants which when they cross will produce seed of desirable type. Such plantings could be established and maintained by vegetative propagation. Proper selection of the parental types may give a considerable degree of hybrid vigor to seed from such plantings.

A third possibility is the use of seed from plantings made up of mass-selected or individually-selected plants having one or more of the desired characteristics.

The vegetative cells of kok-saghyz have 16 chromosomes. The plant will cross only with other species of *Taraxacum* having the same chromosome number (48). Unfortunately none of these species have any appreciable rubber content and nearly all of them have sterility factors. Tetraploid kok-saghyz has been produced by treating seeds or seedlings with colchicine and inducing doubling of chromosome number. Tetraploid plants so produced are reported to be larger and to have latex vessels of greater diameter, as well as heavier seed (40, 47).

However, tetraploids produced in this country by Warmke (65) showed generally decreased rather than increased rubber content. The existence of tetraploid kok-saghyz may open opportunities for crossing kok-saghyz with *T. officinale* and other vigorously growing dandelions which have the same chromosome number as these kok-saghyz tetraploids.

This procedure has been looked upon as perhaps the best method of producing a plant with the vigor characteristic of native dandelions. Greatly increased vigor is a basic requirement in the improvement of kok-saghyz. If the vigor of the presently available medium rubber content strains could be raised to a moderate degree, yields per acre would be increased very materially even without further increase in rubber content. Furthermore, selection on the basis of vigor is a much easier operation and much more quickly productive of increased rubber yields than selections on rubber content or other characters which require detailed analysis.

One of the goals of the program directed toward the improvement of kok-saghyz is to secure a plant with a root habit which will confine the bulk of the rubber produced by the plant within the top 8 to 10 inches of the soil, the depth at which recovery can reasonably be expected. Since much of the rubber is produced in the lower ends of the roots, this would seem to call for branched roots. Experience with the seed from Russia shows clearly that there are strains of kok-saghyz in which branching of the roots is an inherited character. While soil conditions and other environmental and cultural factors tend to modify root form, the problem of selecting the desired types appears to be a simple one.

Once improvement of the plant has produced strains with satisfactory root size and growth habits together with a relatively high rubber content, attention must be given to such factors as the rate and time of rubber synthesis as related to growth and planting and harvesting operations.

SEED IMPROVEMENT

Improvement of the seed is aimed toward insuring heavy yields of uniform, well-filled, viable seed. Both hereditary and environmental factors are concerned in the production of such seed. Koroleva's (20) figures show considerable increase in average seed weight from the progeny of plants grown from selected heavy seed.

Plants grown in Montana from the Russian seed produced heavier seed than those grown from the same source in Minnesota (34p). This heavier seed was tested in several localities and invariably produced stronger plants. The size of the seed, the number of seeds per head, the number of seed heads per plant, all pointed to the environment represented by the irrigated sections of the Missoula Valley of Montana as particularly favorable for seed production.

EQUIPMENT DEVELOPMENT

As has already been pointed out, most of the operations involved in the production of kok-saghyz in Russia were done by hand and with such farm tools as were available. Ramp (33*p*) gives diagrams and a description of a seed-collecting machine developed by Filippov. During the summer and fall of 1942 a trial machine was constructed in accordance with the Russian blueprints and tested at Cass Lake, Minn.

It was obvious from the beginning that if kok-saghyz was to be fitted into American agriculture the various processes in its production would have to be carried out by mechanical means. Fortunately farms here are fairly adequately equipped with implements and machinery necessary for most of the operations of kok-saghyz culture.

Ground preparation required no particular adaptation or changes in existing farm equipment.

As has been described earlier, sowing was accomplished mainly with Planet Junior seed drills after trials had proved them to be better adapted than several other types of drills. At Plainfield, Wis., seed drilling was contracted to the farmer-owner of the land who had a four-unit drill with side attachments for sowing fertilizer at the same time as the seed was sown. The drill was used for sowing carrots and onions and it performed satisfactorily with kok-saghyz.

The project did not purchase fertilizing drills and broadcasting machines but depended on rental from farmers. Later it was found that adequate machinery was not always available and other methods of application had to be improvised. Fertilizer drills were used when obtainable, but grain drills and sugar-beet drills were substituted in some localities. In the Red River Valley of Minnesota there was a shortage of adequate machinery for spreading fertilizer and application was made with a lime spreader. At Saginaw a grain drill was used when the soil was dry enough, but finally it was necessary to resort to hand broadcasting on about 25 acres at slightly more than double the cost of machine application.

Cultivation of kok-saghyz presented no special problems except the need for careful selection of tools and careful operation of more or less standard equipment to achieve cultivation close to the small plants. The problem of cultivating between closely-spaced rows was recognized by Ramp (33*p*) who developed special cultivating attach-

ments for this purpose. The various combinations of tools and attachments which were used have already been described.

The nature of the seed and seed production of kok-saghyz are such as to make seed collection a rather different problem from that encountered in other crops and to demand special machinery.

A motor-propelled two-row seed collector was built by Aamodt of the Lake States Forest Experiment Station and sent to Beltsville, Md., in the winter of 1942-43 for study and comparison with the Russian machine. A newly designed experimental model was then constructed by Ramp, incorporating the best features of the Russian and the Aamodt machines.

This new machine was built to collect seed from four rows at one time. It was tested in Florida in March 1943 and certain changes and adjustments were made. Seventy of these machines were manufactured for distribution to the production areas on the assumption that one machine would handle approximately 10 acres. Knutson (24*p*) found that a maximum of 10 acres could be covered if the machine was operated at 3 miles per hour over $\frac{1}{2}$ -mile-long rows and on reasonably compact soil.

These seed collecting machines were considered generally satisfactory, although operation revealed several deficiencies and suggested various improvements. The machines and the proposed alterations to them have been discussed in detail by Ramp (33*p*).

The only special study in seed cleaning was one undertaken by Kluender (21*p*) at Saginaw, Mich. The fanning mills which were purchased for the project or which were borrowed from forest tree nurseries and used on the kok-saghyz project were clipper mills manufactured by the A. T. Ferrell Co. of Saginaw. Officials of that firm were very cooperative and helpful in working out the problems of seed cleaning through selecting the proper screens and in adjusting the amount of air current used in the blowing process.

As has been discussed by Wales in his report (42*p*) various modifications of locally available equipment were utilized in threshing and cleaning the seed collected in 1943 and 1944.

The nature of the kok-saghyz roots and the requirements of the processing operation seemed to call for the development of new machinery or the modification of root diggers designed for plants with different types of roots. The operation of the various experimental machines has been described in the section on root harvesting. Details of the construction of root harvesting machinery are given by Ramp (33*p*) and Wales (42*p*).

SAMPLING AND ANALYSES

In order to have a satisfactory basis for determining root yields per acre the cooperation of the several agencies was requested in developing sampling techniques for the various experiments. The plans developed were followed in sampling for the calculation of root weight on a per acre basis and for analysis of rubber content. It is now recognized that there were more variables than anticipated, and the sampling was probably none too comprehensive and representative. Nonetheless, the results are indicative of the yields per acre under various conditions.

The most accurate sampling was done in the large fields at Moorhead and Crookston, Minn., where conditions were reasonably stable and the soil fairly uniform throughout the fields. It was determined that 16 samples per 40-acre field, collected in accordance with a previously determined sampling pattern, each sample consisting of plants from 5 linear feet of row, gave a reasonably accurate picture of yield.

In studying the results of sampling it was noted that differences in density of plants per linear foot of row and the row spacings directly determined yields. Some of the factors affecting the density of stands are source of seed, sowing date, amount of seed sown per acre, depth of sowing, fertilizers used, weed growth and weeding damage, and cultivation damage.

In experiments conducted by Zehngraff (*45p*), Kluender (*21p*), and Hurtt (*18p*) the plots were replicated and the samples and plots were staked soon after sowing. This technique provided for most satisfactory sampling.

In connection with the sampling and the determination of the calculated weight of roots per acre, instructions were issued that the roots be topped at $\frac{1}{2}$ inch above the crown, dug to an 8-inch depth, washed to remove adhering soil, dried of excess water, and weighed. Calculated yields were thus based upon the harvestable portion of the root, assuming 100 percent efficiency of the harvesting operation.

The first sampling was done about the middle of September 1943 to obtain some idea as to prospective root yields and the probable rubber content. The results were discouraging since the indicated yields were extremely small and considerably under the estimated average of 4,000 pounds per acre. The assays indicated low rubber content.

Zehngraff (*45p*) took a number of random samples in early September and again in late October. In every case the indicated yield

of the later samplings was more than double that determined some 4½ to 6 weeks earlier. Knutson (24*p*) presents a table which shows the comparative weights indicated by the September and October sampling and confirms Zehngraff's findings.

Table 9, page 144, shows the calculated yields per acre on the various fields as of late October 1943.

The spring 1944 analyses indicate little or no increase in rubber percentage from late fall to early spring (prior to any new growth). After new growth begins in the spring, analyses indicate that the rubber percentage is about 2 percent higher. Whether there is an actual increase of rubber or simply a reduction in the dry weight has not been determined.

There is a further increase in rubber percentage in June before the "glove" is sloughed off. It is probable that this percentage increase represents an actual accumulation of rubber. Steinbauer (37*p*) has shown that stored substances are being replenished at this period in the life of the plant and sampling indicates that the weight of roots per acre increases approximately 50 percent over that of early spring.

The results of the analyses of samples taken during 1943 and 1944 are given in detail in Wales' report (42*p*).

SUMMARY OF THE EXPERIMENTAL WORK

The primary objective of the Emergency Rubber Project (kok-saghyz) was to determine, by actual production experience, whether the growing of kok-saghyz in this country as an emergency source of rubber was feasible.

It was the general thought that a single season's effort would reveal the major problems. However, by midsummer of 1943 it was recognized that much of the essential information could not be secured by the close of that season.

A continuing program of experimentation and research was outlined. Such a program as part of the Emergency Rubber Project was not approved and liquidation not later than June 30, 1944, became necessary.

A brief summary of what was learned about kok-saghyz and its culture during the period of active investigation, from May 1942 to June 1944, follows.

Where the crop can be grown and soils required.—Studies indicate that kok-saghyz for root and rubber production can be grown best in Michigan, Wisconsin, and Minnesota. Areas in New England, New York, Montana, and Oregon were investigated extensively in 1942 and 1943, but with inconclusive results. The results of indicator plantings suggested that a few other areas might be adaptable but that many are not.

Best seed production was secured in the irrigated valleys of western Montana.

Preliminary indications are that good root and fair seed crops can be produced on the muck lands of southern Florida during the winter months.

It is apparent that kok-saghyz requires a good mineral soil, high in organic content, or a peat soil which has been cultivated for several years. Heavy soils, poorly drained areas, those excessively stony, or fields with slopes over 5 percent, have proved undesirable. The crop needs an unusually well-prepared seedbed.

Some 18 soil types were tested in the Northern States and an additional 7 soil types tested in the Southern States.

Kok-saghyz failed as a crop in one field because the preponderate rogue population was not recognized, in another because of excess weeds, and in two others by reason of unfavorable weather conditions.

Other factors, including crusting of the soil, improper drainage, excess alkalinity, and flooding of fields, were responsible for partial failures.

In 1943, 646 acres or 86 percent of the projected 750 acres was actually sown. Of the original sowings, 28 percent was lost for various reasons but 108 acres were reseeded although some of the reseeding was done too late to secure adequate root production by the close of the growing season. About 522 acres were brought through to harvest. This percentage of accomplishment compares favorably with the accomplishments of farmers with other crops in the area during the same season.

Overwinter losses.—Data on overwinter losses in the North were obtained in the spring of 1944. Likewise, a study was made of the comparative value of fall seeding versus spring seeding. Wind erosion of the fall-seeded tracts was somewhat greater than anticipated. Further work should be done in determining how the fields can be left rough to reduce the effect of wind erosion.

It was determined that roguing is necessary in second-year stands because of regrowth of roots cut off the previous year.

Yields per acre—roots and rubber.—On the basis of samples rather than averages of field production, yields up to 7,900 pounds (green weight) of roots per acre have been recorded. Careful calculations place the average production from the seed stocks used at 4,000 to 5,000 pounds per acre on the basis of crops sown in the spring and harvested in the fall of the same year. When air-dried, the crop reduces to about 20 percent of its original weight. Laboratory analyses showed up to 7½ percent rubber content of dried roots, the average being about 4½ percent. Occasional samples ran above 7½ percent.

On the basis of the indicated average, yields were about 45 pounds of rubber per acre. Reports of Russian production over large acreages indicate an average of 3,000 pounds of fresh roots yielding from 30 to 60 pounds of rubber per acre.

Whether there is an actual increase in rubber yield per acre from roots dug in the next spring following their seeding is not yet known. The high rubber content of samples of second-year roots analyzed suggests such a possibility. Rubber percentages from 6.0 to 9.3 percent were recorded, but the yield per acre of the roots in the second spring was not determined.

Root production in the South was fair, but the rubber content of Florida grown roots was somewhat low. Earlier seeding might bring about increases both in root volume and rubber content.

Yields per acre—seed.—Small irrigated acreages in protected valleys in Montana produced at the rate of 14 pounds of seed per acre during

their first year and 150 pounds per acre the second season. Lake States seed production from first season plants was from 10 to 20 pounds per acre, stepping up to 15 to 30 pounds per acre the second season. These figures compare with a reported maximum of 27 to 30 pounds of seed per acre in Russian plantings.

At locations in California and in Arizona, Texas, and Florida it was demonstrated that reasonably good seed yields could be secured for shipment north for planting in the same season. It should be noted that the overwinter production of seed applies only for the first-year-flowering plants, particularly in Florida, since the plants cannot be held over summer in that climate.

Cultural methods.—Cultural methods were fairly satisfactorily worked out although many problems were not attacked. It was determined that methods used with field truck crops are generally satisfactory in handling kok-saghyz. However, the slow growth of this characteristically weak plant makes its culture difficult and more time- and labor-consuming than that of comparable crops.

Machinery and equipment development.—Excellent progress was made in machinery development, partly by modifying standard attachments for cultivating.

The root harvesting machine worked satisfactorily in light sandy soil, but not where the soil was very compact or wet. Under reasonably heavy soil conditions in good weather the machine was approximately 50-percent efficient. Experiments in using the weeding knives on the cultivator bar for topping led to a satisfactory solution of this problem.

The pilot extraction mill was not completed during 1943 because of priority difficulties in securing necessary parts and equipment. However, extraction processes were worked out in considerable detail and roots were furnished the pilot plant as required for experimental work. Little rubber was accumulated until the spring of 1944.

Seed collection requiring, according to Russian papers, six to eight workers per acre per day during the seed-bearing season was simplified by the development of a four-row mechanical seed picker that in its first season testing collected 50 to 70 percent of available seed yet used only two workers per 12 acres.

It was demonstrated that standard seed-cleaning mills can be readily adapted to the cleaning of kok-saghyz seed. However, drying devices should be developed in order to dry the pappus to a brittle condition quickly so that the seed and pappus can be separated in a cottonseed hopper. In any large seed production program the drying, threshing, and cleaning operation should be developed as a continuous process with full provision to handle the dust and fine pappus particles so that laborers will be able to work without respirators.

Rubber extraction.—A comparatively simple method for the recovery of rubber from kok-saghyz was developed. The method also calls for recovery of fermentable carbohydrates from fall-harvested roots, but not from spring-harvested roots as the carbohydrate content of the latter is too low to justify such recovery. The carbohydrates are recovered by countercurrent leaching with hot water and they may then be fermented to alcohol or other products.

The extraction process consists of subjecting the roots to a hot water extraction process to soften the roots, and in the case of those harvested in the fall, to recover the carbohydrates. The roots thus softened are then pebble-milled with water to disengage plant tissues and to agglomerate the rubber. The slurry from this milling is diluted with water and passed over a vibrating screen which eliminates everything except the rubber and some root "skins." A second pebble-milling with water frees the rubber from root "skins." The rubber is finally separated from the "skins" by flotation. It is then washed and an antioxidant incorporated. The rubber is finally dried in a through-circulation belt drier.

Factory fabrication of tires and actual road tests showed that kok-saghyz rubber performs as satisfactorily as hevea rubber in the carcasses of heavy duty tires. Synthetic rubber is not satisfactory for this purpose. With our present limited knowledge on compounding of kok-saghyz rubber, its tread wear is slightly less than that of hevea rubber. Kok-saghyz rubber is much superior to that from guayule.

PROPOSALS FOR FURTHER INVESTIGATIONS

The seed stocks obtained from Russia were extremely heterogeneous, containing not only kok-saghyz showing wide ranges in rubber content and root size but also many rogues (dandelions with very little or no rubber). Elimination of these rogue plants brings about an appreciable increase in per acre yields. Roots selected for high rubber content show percentages running from 12 to 22 on a dry weight basis. Selection studies also indicate the possibility of greatly increasing individual root size.

Increasing both root yields and rubber content significantly would require a selection and breeding program covering a period of many years.

If increases in rubber content and root yield of kok-saghyz can be accompanied by marked improvement in the general vigor of the plant, economical production of the crop may become a distinct possibility.

If an attempt at commercial production of rubber from improved kok-saghyz plants is to be undertaken there should be further investigation of several problems which remained unsolved at the time the Emergency Rubber Project (kok-saghyz) was terminated.

Climate and soil range.—The testing of soils in 1943–44 was nowhere near complete and was done under only one set of weather conditions, a wet, cold spring followed by a period of numerous heavy rains. Within the area now known to be favorable for production, further trials should be made and should include some of the lighter sandy loam soils as well as some of the heavier soils approaching the clay type which did not give good results during the very wet season of 1943. Particular attention should also be given to trials on various soils under somewhat different climatic conditions.

Ground preparation.—There is no short cut to the use of the very best agricultural practices in preparing a fine seedbed for kok-saghyz. The full value of fall plowing and of summer fallowing has not been tested.

In 1943 frequent heavy rains minimized the importance of maintaining capillarity and holding moisture near the surface in order to secure good germination. Ground preparation and cultural practices for this purpose need further investigation.

Further experimental work in determining how best to leave the surface of the ground between the drilled rows so as to reduce the amount of soil movement by heavy winds is desirable.

Seed storage.—Further investigation should be made of the storage of seed even though it has been shown that storage of seed with a moisture content of about 9 percent in sealed containers is good practice. Can seed be held in bags in a dry place from the period of collection to the next sowing season without material loss of vitality as is claimed by the Russians?

Storage tests are being conducted by the Forest Service and will be continued for several years. Seed is being held in sealed and open containers at low temperatures and at ordinary fluctuating room temperatures.

Seed treatment.—The need for presowing treatment has not been definitely established for seed of different ages and origins. It has been shown that chilling or soaking before sowing is a satisfactory means of breaking dormancy of the seed. It has not been determined how much the pretreated seed can be dried without inducing a return to dormancy, or whether there is any substitute for holding treated seed at a temperature close to freezing. Further attention should be paid to chemical methods of seed treatment to break dormancy.

Spacing and density.—Further study should be made of various row spacings. Investigations should be based on the economy of cultivation and weeding and the damage done by weeders, consider the reduced production secured from the wider spacing intervals and take into account the standard practices with other crops in the same region.

The best density per linear foot of row under various conditions has not been fully determined. In most of the experimental production root yields increased with the number of plants per linear foot. Indications were that 15 to 35 plants per linear foot might represent the optimum density of stands.

Seed collection.—Further study should be made of the economics of collecting seed throughout the period of seed production or simply during the period of maximum production, and the comparative cost and effectiveness of two daily pickings compared with one should be studied. Seed pickers must be made more durable, more easily adjusted in height and gauge, and more efficient.

Vegetative propagation.—Vegetative propagation should be investigated further. The cost of establishing stands by this means may be justified by reduction in the cost of preparing the soil and planting the material and the securing of a sufficiently dense stand of plants which grow more vigorously.

Cultivation and weeding.—Increased efforts should be made in every direction likely to reduce weeding. The possibility of using chemical weeding controls should be given further consideration.

Insect and disease problems.—With the development of any large scale production of kok-saghyz careful observations should be made to insure early recognition of any diseases or insects liable to become serious pests and to develop control measures where possible.

Root harvesting.—The economics of harvesting roots at various seasons should be further studied. Particular attention must be given to the time of harvesting in relation to rubber accumulation, storage in the plant of usable byproducts, seed production, and the demands of year-long processing operations.

Additional work is required in developing harvesting machinery that can top, lift, clean, and collect roots in a single mechanical operation.

Root storage.—Storage of fresh and dried roots should be studied further, with particular relation to the extraction process and the products to be extracted. Study should be made of the proposal that roots be ensiled as a means of storage.

Adequate drying and storage facilities and processes must be developed in relation to year-round mill operations. It is essential to recognize that such a development must be on an extremely large scale with complete mechanization of handling phases.

The possibility of crushing fresh roots prior to drying or developing other mechanical or chemical means of reducing bulk and partially processing roots before storage should be investigated.

Extraction.—Further study of the extraction process should be made to effect simplification, reduce costs, and to adapt it to the utilization of both fresh and stored roots and to the variation in form, composition, and incidental contamination which will inevitably occur in any large scale agricultural enterprise.

Testing, fabrication, and utilization.—While the preliminary tests were not extensive, they indicate that kok-saghyz rubber is the best available natural rubber substitute for hevea rubber. Tires made from it proved entirely satisfactory.

Prior to any large-scale commercial production, further tests should be made to determine the extent of its usefulness. Concurrently, experimentation should be conducted to determine the formulas and process modifications which will yield the most satisfactory results.

Attention should also be given to the possibility of modifying the extraction process or adding operations designed to improve the quality of the hydrocarbon extracted.

THE POTENTIAL VALUE OF KOK-SAGHYZ AS A DOMESTIC SOURCE OF NATURAL RUBBER

The experience of the Emergency Rubber Project (kok-saghyz) has demonstrated clearly that kok-saghyz represents a source of excellent natural rubber and holds good possibilities for the production of natural rubber within the borders of the United States.

Further, the plant can be grown as a crop over a large area within this country by simply adapting cultural procedures used with other crops and developing machinery to mechanize its handling.

However, the cost of growing kok-saghyz from the seed stocks available in 1943-44 makes its use inadvisable except in the most dire emergency.

Any future use of the plant as a crop depends upon great improvement in its vigor, size, and rubber content. Such improvement can be made over a period of 8 to 10 years with relatively little difficulty and without the expenditure of great sums of money.

The hereditary background of kok-saghyz and its reproductive characteristics lend themselves readily to a program of plant improvement and give promise of very substantial gains. From what has been done with other crop plants less favorably endowed with hereditary variability and with reproductive characteristics much more limiting in regard to selection and breeding, it can be conservatively estimated that improvement yielding as much as a tenfold or twelvefold increase in rubber production per acre can be expected.

Inasmuch as great improvement of the plant is the key to its possible exploitation as a domestic rubber crop and since such improvement may be expected to modify markedly the details of its culture, continued experimentation can only be justified on the basis of its direct contribution to such plant improvement.

A more vigorous, higher yielding kok-saghyz plant can come only as the product of a planned program of selection and breeding. Some progress in selection and breeding has already been made but any considerable future progress depends upon developing a broader foundation of knowledge of the biological characteristics of the plant upon which to build a properly oriented improvement program.

Taraxacum kok-saghyz has been known for only slightly more than a decade. Except for some work by Russian investigators indicating

that it crosses readily with certain other species, no examination of its position as a species or its relations to other species has been made. Knowledge of these relations may be of importance since many other species of *Taraxacum* possess characteristics which would be of great value in a plant being exploited as a commercial source of rubber. Familiarity with the many species of *Taraxacum* and their geographical distribution might reveal other characteristics of significance and possibly shed light upon the origin of the rubber-bearing species, *kok-saghyz*.

Successful culture of *kok-saghyz* demands a plant with growth characteristics which make possible easy cultivation and harvesting. The extent of hereditary control of general growth habits, vigor, top and root form, and the effect of environmental factors upon these characteristics must be worked out in detail. Knowledge of the anatomy of the plant and the formation and development of the latex system may indicate paths which should be followed in attempting to increase rubber content.

One of the most distinctive characteristics of the present stocks of *kok-saghyz* is the extreme variability in leaf form, not only among plants but in the same plant at different stages in its development. This variability should be studied carefully to permit segregation of strains and to determine whether there is correlation between any particular leaf shapes and desirable or undesirable characteristics so that such leaf shapes could be used as tags in selection and breeding. The effect of different environments on such leaf variations would also have to be determined.

The variability in leaf form is almost matched by variability in reproductive habits. Within what are commonly accepted as the species limits are found plants which flower during the first season after planting, others which do not flower until the second season; some which flower almost continuously, others which appear to have definite cycles of flowering; self-sterile plants which never set seed to their own pollen, others which are at least partially self-fertile. The significance of these variations and their usefulness in a practical improvement program can be resolved only by careful study.

The maximum improvement of *kok-saghyz* as a rubber-producing plant depends upon gaining knowledge regarding the formation of latex and rubber and their role in the life of the plant. Despite the fact that latex occurs in hundreds of species of plants, in many different families and of widely varying origins, its role is still unknown. The function of rubber, a principal constituent of latex, also remains undetermined, as does the method of its synthesis and its exact chemical nature.

Kok-saghyz, being an easily handled herbaceous plant and producing large amounts of rubber-bearing latex in a readily accessible vessel system, and lending itself admirably to experimental work, presents a peculiarly favorable opportunity for study of fundamental problems of latex and rubber synthesis and their relations to other processes in the development of the plant.*

Fruitful investigations of such a plant may thus add considerably to the storehouse of knowledge of essential information concerning rubber formation in plants, in addition to pointing the way for the improvement of kok-saghyz itself as a source of rubber.

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